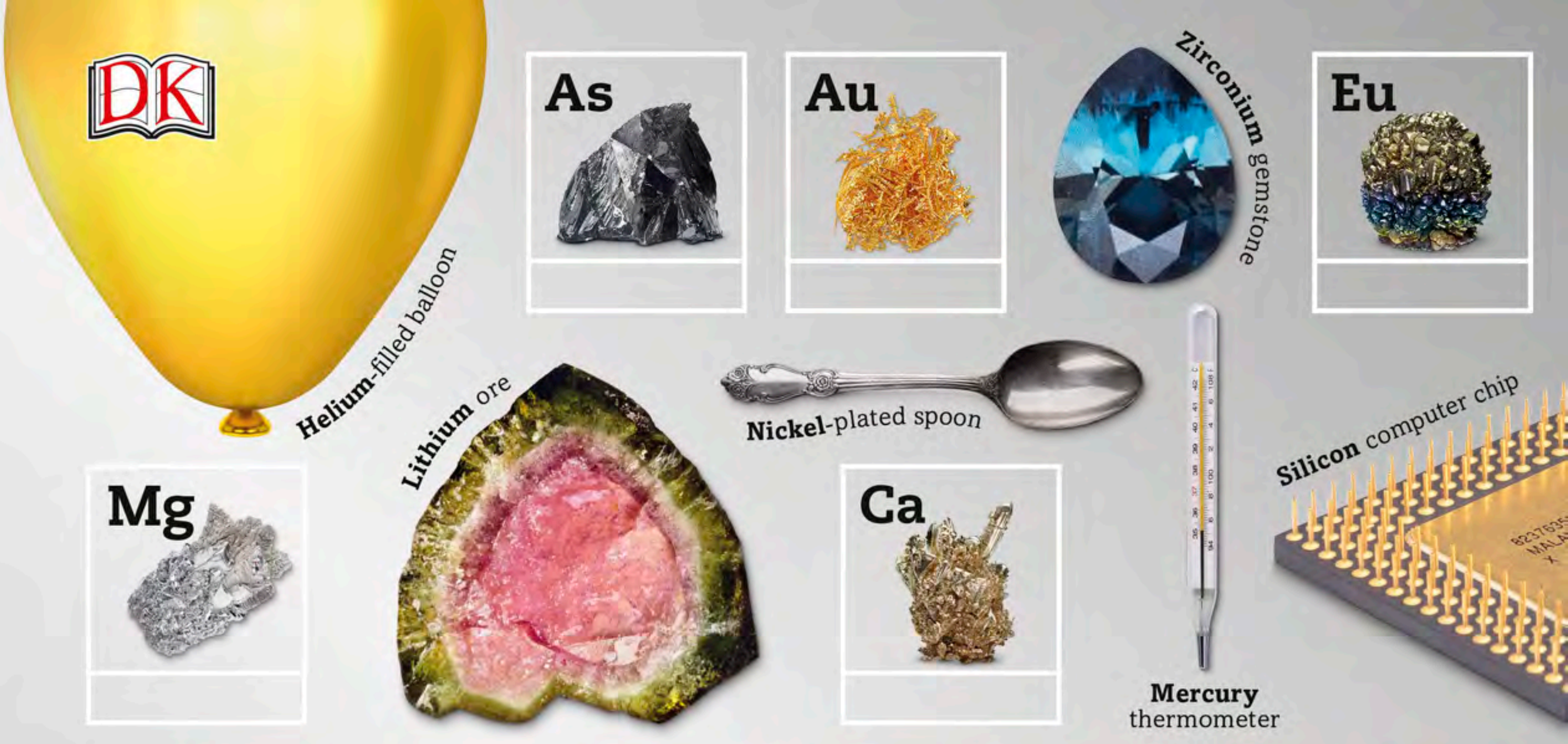
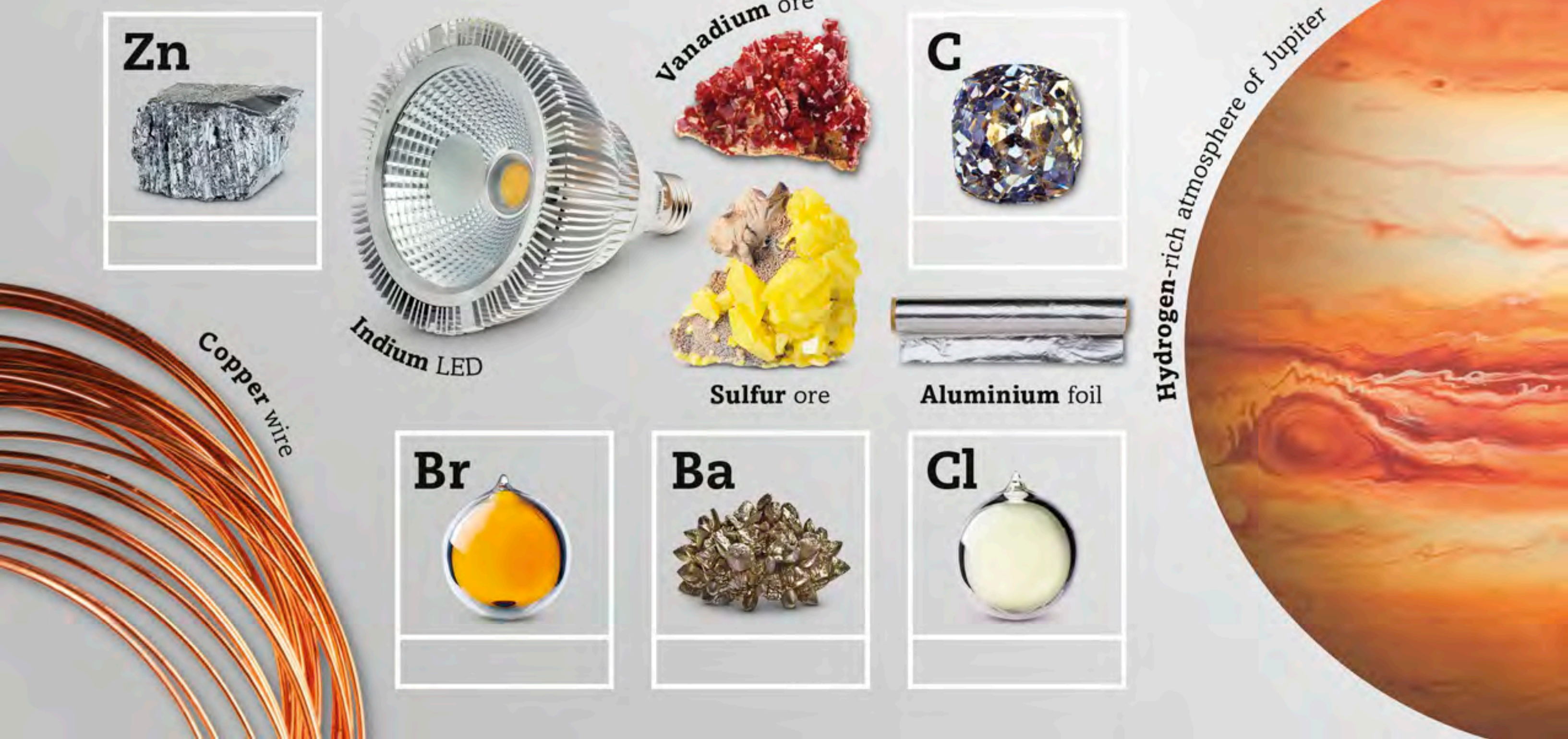


THE PERIODIC TABLE BOOK

A VISUAL ENCYCLOPEDIA OF THE ELEMENTS



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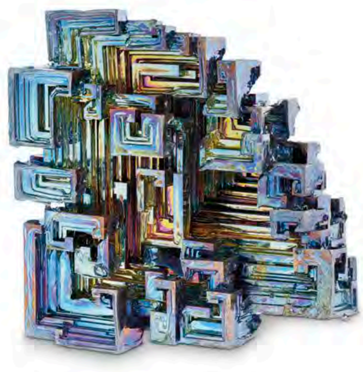


Chunk of yttrium

Chunk of silver

Zirconium crystal bar

Foreword

Everything in nature, from the mountains and the oceans to the air we breathe and food we eat are made up of simple substances called elements. You may have already heard of several of them, including gold, iron, oxygen, and helium, but these are just four out of a total of 118. Many have unique – and sometimes surprising – chemical and physical properties. Gallium, for example, is a solid but melts in your hand. A compound of sulfur gives off a nasty smell of rotten eggs. Fluorine is a gas that can burn a hole straight through concrete!

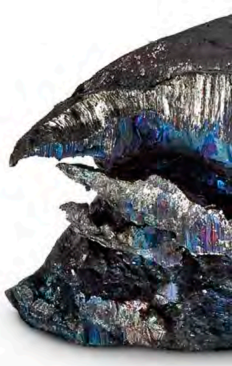
The elements are rarely found in their pure form. Mostly, they are combined with each other to make compounds, which make up substances around us. For example, hydrogen and oxygen make water, sodium and chlorine form salt, and carbon is found in millions of compounds, many of which – including proteins and sugars – make our bodies work.

To find out more about the elements, we need to take a good look at the periodic table. This is used by scientists around the world to list and detail the elements. It shows the key information

Nickel balls

Cube of melting gallium

Iodine in a glass sphere



Barium crystals

Chunk of grey selenium

Magnesium crystals

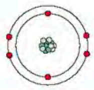
Osmium pellet

for each element, grouping them into similar types. With this information, we can use the elements to make many things we need: a fluorine compound in toothpastes toughens our teeth and silicon crystals engineered into microchips operate our gadgets and phones.

Every element has its own story of where it comes from, what it can do, and how we use it. Let's begin a tour of every element one by one. It's going to be a fascinating journey.

Tom Jackson

Throughout this book you will find boxes with the following symbols. This is what each of them mean.

	This shows the structure of an atom of an element, with the nucleus (made of protons and neutrons) at the centre and electrons surrounding it in their shells.
−	Electron
+	Proton
○	Neutron
State	The state of the element at a temperature of 20°C (28°F). It can be a liquid, solid, or gas.
Discovery	This details the year in which the element was discovered.

Chunk of uranium

Gold crystals

Thulium crystals

Calcium crystals

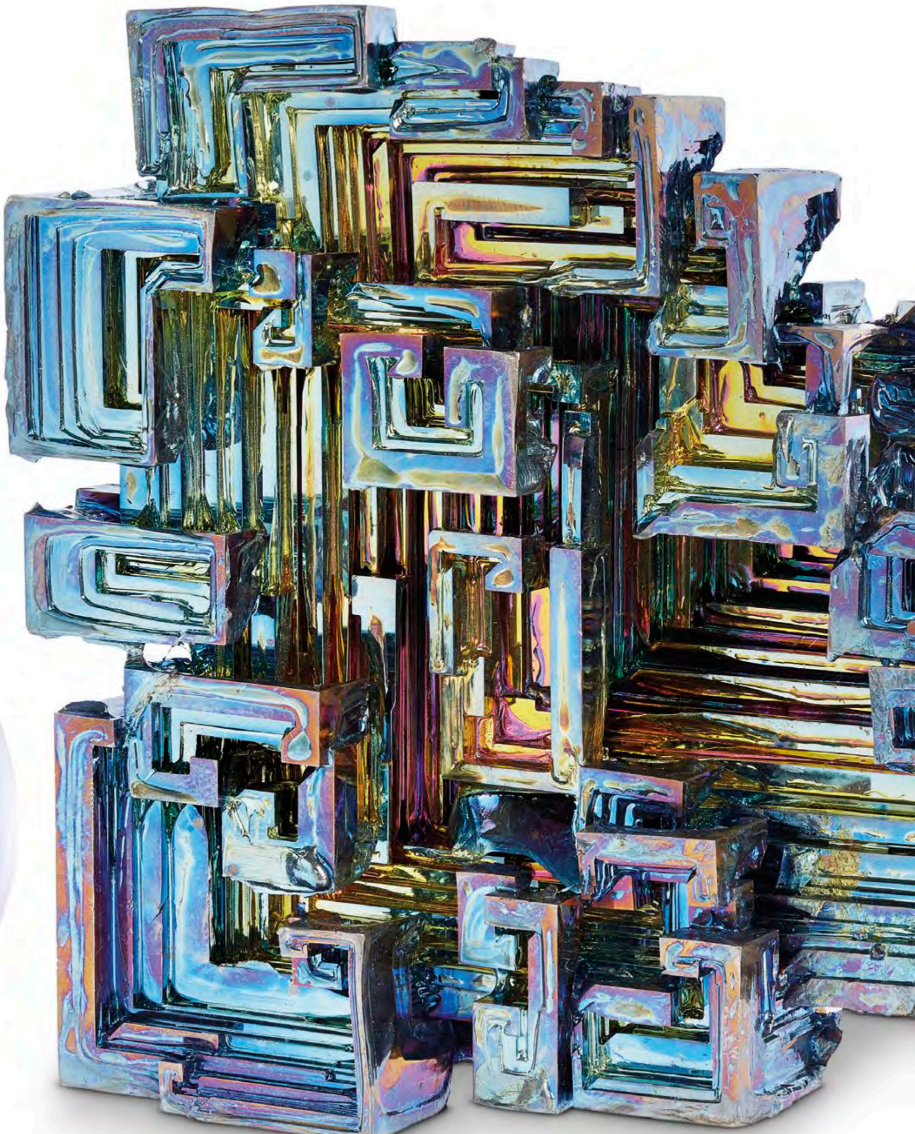
Elemental building blocks

Elements are everywhere: some you can see, like gold, others are almost invisible, like oxygen gas. An element is a substance that cannot be broken up into simpler ingredients. Each one is made up of tiny building blocks called atoms, which are unique for every element. Most elements are joined with other elements to make compounds, which are made by combining two or more elements. This includes water, which is a compound of hydrogen and oxygen.

Elements in our world

There are 118 elements in the periodic table; 92 of them are found in nature, while the others are made by humans. Every element is unique. Most of the elements are solids, like the metals. At room temperature, 11 elements are gases, while bromine and mercury are the only two liquids.

Bromine liquid with bromine gas



Bismuth crystals

Earth

Water

Air

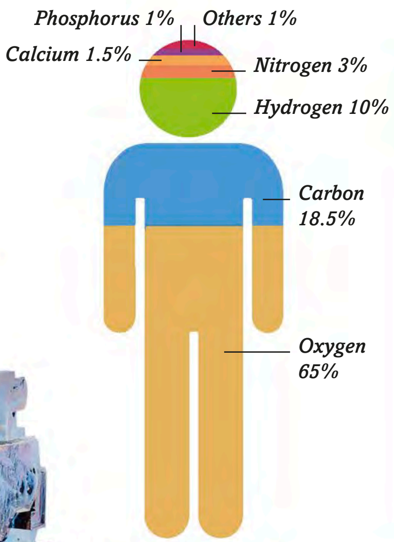
Fire

Ancient ideas

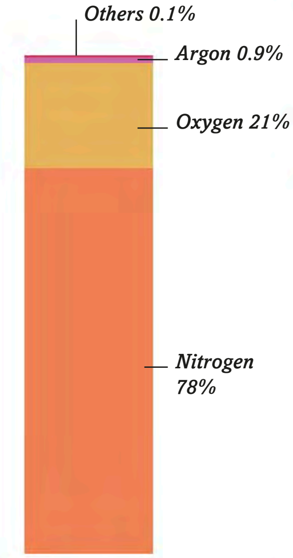
The idea of elements is very old, dating back about 2,600 years to ancient Greece. However, Greek thinkers believed that the world was made of just four elements: earth, water, fire, and air. Empedocles, an influential scholar, was the first to propose that these elements made up all structures. Only much later did scientists learn that none of these are actually elements. For thousands of years, everybody from ancient Egyptian priests to medieval European alchemists, speculated about the definiton and classification of an element.

Elements in and around us

About 99 per cent of the human body is made from just six elements, though they are combined together to form thousands of different compounds. On the other hand, Earth's atmosphere is a mixture of gases, most of which are pure elements. About 99 per cent of the air is made from nitrogen and oxygen.



Human body



Earth's atmosphere

Gold crystals

Iranian alchemists in their workshop

Alchemy and mysticism

Chemists are scientists who study elements and compounds. However, before they existed, the alchemists were medieval researchers. Believing in a mixture of science and magic, alchemists tried to change ordinary metals (such as lead) into gold. They failed because elements cannot be changed from one type to another. But, in the process, they discovered many new elements and developed several processes that chemists still use today.

ROBERT BOYLE

The first person to use science to understand the elements was the Irish scientist and inventor Robert Boyle. He pursued science through reason, and in the 1660s he performed the first chemistry experiments to show that much of what the alchemists believed was wrong.

Chemical discoveries

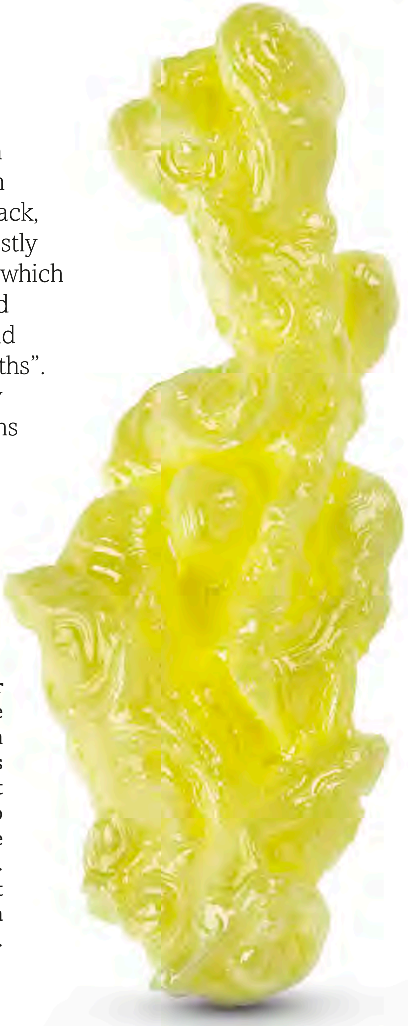
Humphry Davy
In the early 19th century, the English scientist Humphry Davy discovered several new metals. He used a revolutionary process called electrolysis, in which electric currents split chemical compounds into their elements. Davy discovered a total of nine new elements, including magnesium, potassium, and calcium.

The ancient concept of four elements – earth, water, fire, and air – expanded to a belief that every substance on Earth was made from a mixture of these elements. However, many substances including mercury, sulfur, and gold did not fit this idea. Over the last 300 years, chemists have followed a long series of clues to reveal the true nature of elements, their atoms, and what happens to them during chemical reactions.

Pioneering chemists

Many of the first breakthroughs in chemistry came in the 1700s, from investigations into the composition of air. Chemists such as Joseph Black, Henry Cavendish, and Joseph Priestly discovered several different "airs", which we now call gases. They also found that the gases could react with solid substances, which they called "earths". These discoveries began a journey that revealed that there were dozens of elements, not just four. Today, scientists have identified 118 elements, but more may be discovered in time.

Antoine Lavoisier
In 1777, the French scientist Antoine Lavoisier proved that sulfur was an element. This yellow substance was familiar for thousands of years, but Lavoisier performed experiments to show that it was a simple substance that could not be divided up any further. In the same year, he also found out that water was not an element, but a compound of hydrogen and oxygen.



Granule of pure sulfur

Magnesium crystals

JOHN DALTON

Like many scientists of his day, the English scientist John Dalton already believed that matter must be made of tiny particles. In 1803, he began to think about how these particles might join together. He came to realize that there are different particles for every element, and that the particles of one element all have the same mass. He also realized that the particles of different elements combine in simple proportions to make compounds. So, for example, the particles of the elements carbon and oxygen can combine to make carbon monoxide. He suggested that during a chemical reaction, the particles rearrange to make compounds. He formulated the first modern theory of atoms.

Dalton's table of elements

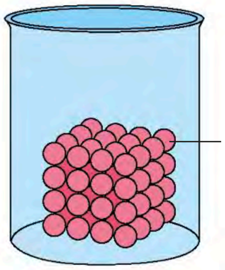
Jacob Berzelius
In the early 1800s, the Swedish doctor Jacob Berzelius investigated chemicals in rocks and minerals. He found two minerals that contained new elements. He named these elements cerium (after Ceres, the dwarf planet) and thorium (after Thor, the Viking god of thunder). Berzelius also invented a system of using symbols and numbers that chemists still use to identify elements and compounds today.

Chunk of pure cerium

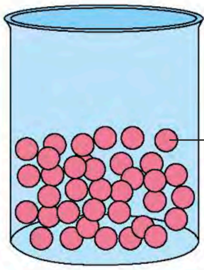
Pure caesium inside a sealed container

States of matter

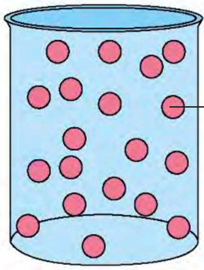
Elements can exist in three states of matter: solid, liquid, and gas. At room temperature, most elements are solids, 11 are gases, and only two are liquids. However, elements can change from one state into another. These changes don't alter the atoms of these elements, but arrange them in different ways.



In a solid, all the atoms are attracted to each other and locked in position.



In a liquid, the atoms begin to move around as the attraction between them weakens.



In a gas, the atoms are weakly attracted to each other, so they all move in different directions.

Robert Bunsen
The German chemist Robert Bunsen is best known for inventing a gas burner that is often used in laboratories. In the 1850s, Bunsen used such a burner – which produced a hot, clean flame – to study the unique flame colours produced by different elements. When an unknown substance made bright blue flames, he named it caesium, meaning "sky blue".

Inside an atom

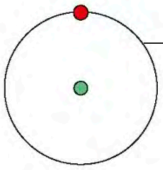
An atom is the smallest unit of an element. Atoms are too small to see (even with the most powerful microscopes) but they are everywhere. They consist of smaller particles called protons, neutrons, and electrons. Every element has a unique number of protons.

What's the atomic number?

The number of protons in an atom of an element is called the atomic number. The atomic number of an atom identifies the element it belongs to. Every atom also has an equal number of electrons. For elements found naturally on Earth, hydrogen has the smallest atomic number (1), while uranium atoms have the highest atomic number (92).

1
H

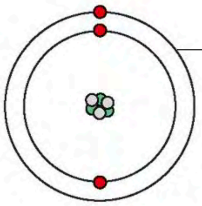
Atomic number



This shell is the space in the hydrogen atom where one electron circles the proton at the centre of the atom.

Hydrogen atom

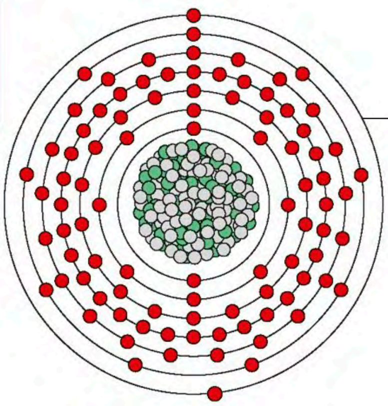
3
Li



In a lithium atom, two shells house three electrons, which circle the protons and neutrons at the centre.

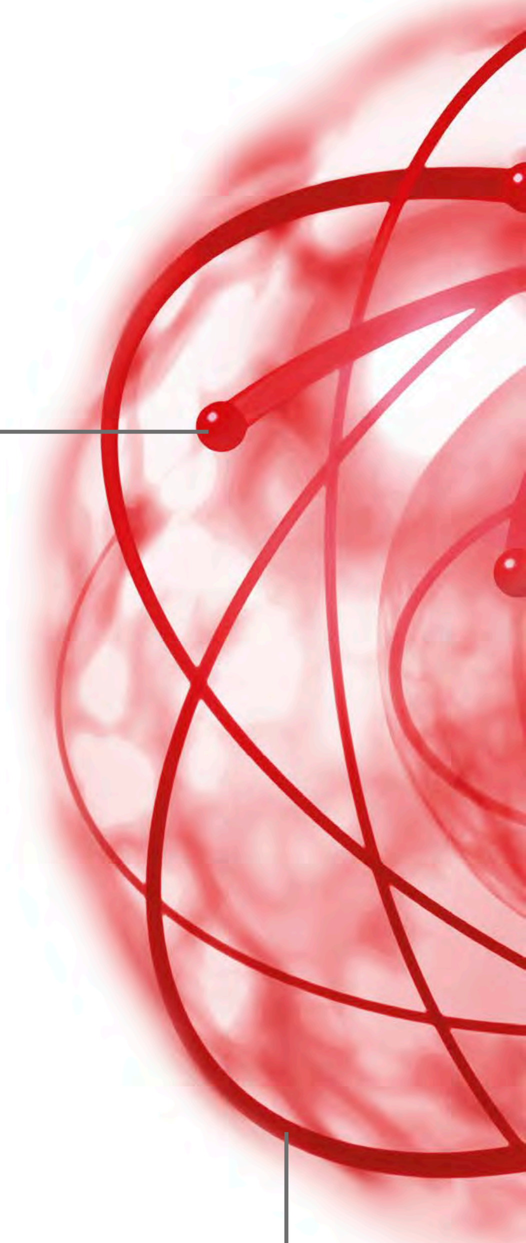
Lithium atom

92
U



Seven shells house the 92 electrons in a uranium atom.

Uranium atom

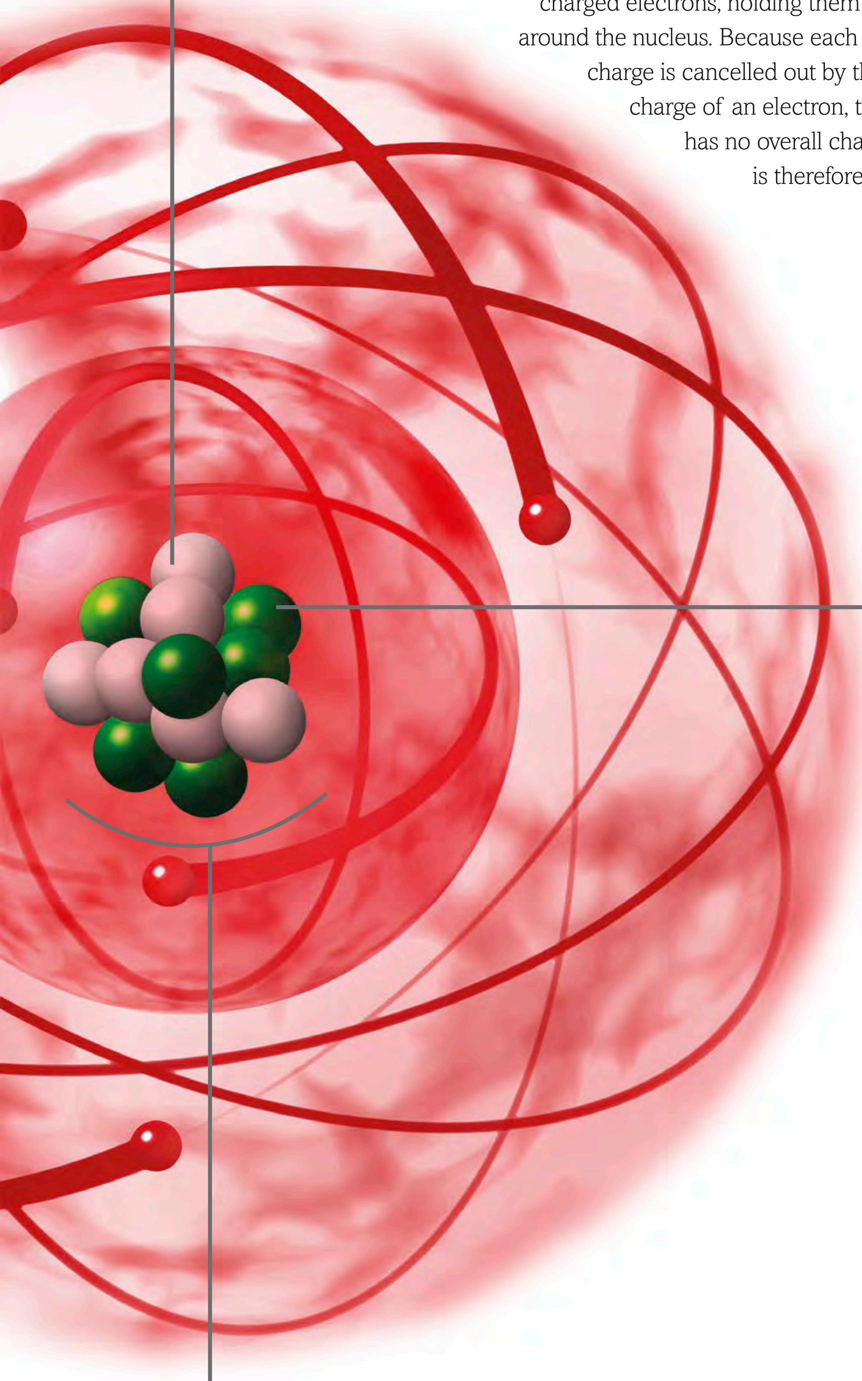


Electron ❯ The tiny, negatively charged particles in an atom are called electrons. They are involved in the way the atoms of an element react and form bonds with the atoms of other elements.

Shell ❯ The electrons in an atom move around the nucleus. They are arranged in layers called shells. When reacting with each other, atoms tend to fill up their outer shells to become more stable.

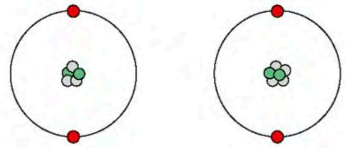
Neutron ❯ As its name suggests, neutrons are neutral particles, which means they do not have an electric charge. A neutron weighs the same as a proton, and much more than a electron.

Proton ❯ Protons have a positive electric charge. This charge attracts the negatively charged electrons, holding them in place around the nucleus. Because each proton's charge is cancelled out by the equal charge of an electron, the atom has no overall charge, and is therefore neutral.



Nucleus ❯ The central core, or nucleus, of an atom is made up of protons and neutrons. Nearly all the mass of the atom is packed into the nucleus, and this gives every element a unique atomic mass.

Atomic facts



Isotopes

While every element has a unique number of electrons and protons in its atoms, the number of neutrons can vary. These different forms are called isotopes. For example, helium has two isotopes: one contains three neutrons (He-3), the other has four (He-4).

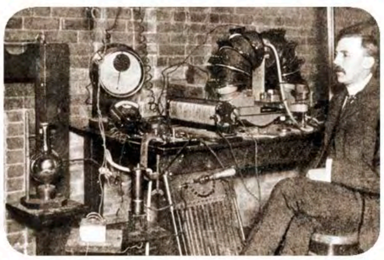
Electromagnet attracts metal pieces

Electromagnetism

Atoms work like tiny magnets. A force called electromagnetism holds them together. It makes particles with opposite charges, such as protons and electrons, attract each other. Those with similar charges repel each other. A magnet is an object in which the magnetic forces of the atoms attract and repel other objects. An electromagnet develops magnetism when an electric current runs through it.

ATOMIC PIONEERS

During his atomic research in the early 20th century, Sir Ernest Rutherford, a New Zealand scientist, expanded our understanding of the structure of atoms. He discovered protons and proved that they were located in an atom's nucleus.



Sir Ernest Rutherford

Periodic table of elements

The periodic table is a useful way of organizing the elements. It arranges the elements in order of their atomic number, which is the number of protons in the nucleus of an atom, and is unique to every element. The table also divides the elements into rows, called "periods", and columns, called "groups". Dmitri Mendeleev, the chemist who devised the table, arranged the elements based on the similarity of certain physical and chemical properties.

1 H 1.0079											
3 Li 6.941	4 Be 9.0122										
11 Na 22.990	12 Mg 24.305										
19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.867	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.39
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (96)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41
55 Cs 132.91	56 Ba 137.33	57-71 La-Lu	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59
87 Fr (223)	88 Ra (226)	89-103 Ac-Lr	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (281)	111 Rg (272)	112 Cn 285
			57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm (150.36)	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93
			89 Ac (227)	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)

The actinides and the lanthanides *are placed between the alkaline earth metals and the transition metals, but have been moved below to give them more space.*

KEY

- Hydrogen
- Alkali Metals
- Alkaline Earth Metals
- Transition Metals
- Lanthanides
- Actinides
- The Boron Group
- The Carbon Group
- The Nitrogen Group
- The Oxygen Group
- The Halogen Group
- Noble Gases

Elements of this group *are semi-metals (elements with the properties of metals and non-metals): they are shiny like metals but crumble easily like non-metals.*

This group *contains the noble gases, which never form bonds with other elements, and are unreactive.*

					2 He 4.0026
5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.065	17 Cl 35.453	18 Ar 39.948
31 Ga 69.723	32 Ge 72.64	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
81 Tl 204.38	82 Pb 207.2	83 Bi 208.96	84 Po (209)	85 At (210)	86 Rn (222)
113 Nh 284	114 Fl 289	115 Mc 288	116 Lv 293	117 Ts 294	118 Og 294
66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

Reading the table

Element symbol

Every element has a unique symbol of one or two letters. These symbols ensure that scientists who speak different languages do not get confused while describing the same element.

3

Li

6.941

The atomic number is the number of protons in the nucleus of this element's atoms.

The first letter of a symbol is always a capital, but the second is lower case.

The atomic mass number is the average of all the atoms of the element. It is not a whole number because there are different isotopes (forms) of each element, each with a different number of neutrons.

Periods

Elements in the same period, or row, have the same number of electron shells in their atoms. So elements in period one have one electron shell, while those in period six have six electron shells.

Periods run from left to right.

Groups run from top to bottom.

Groups

Members of a group, or column, all have the same number of electrons in their outermost shell. For example, group one elements have one outer electron, while group eight elements have eight outer electrons.

DMITRI MENDELEEV

The periodic table was developed by the Russian chemist Dmitri Mendeleev in 1869. Others had tried before, but his table was periodic, or repeating, because the characteristics of elements follow a pattern. The table was incomplete as some elements had not yet been discovered. However, Mendeleev predicted the positions of the missing elements, and was proved right when they were finally isolated many years later.

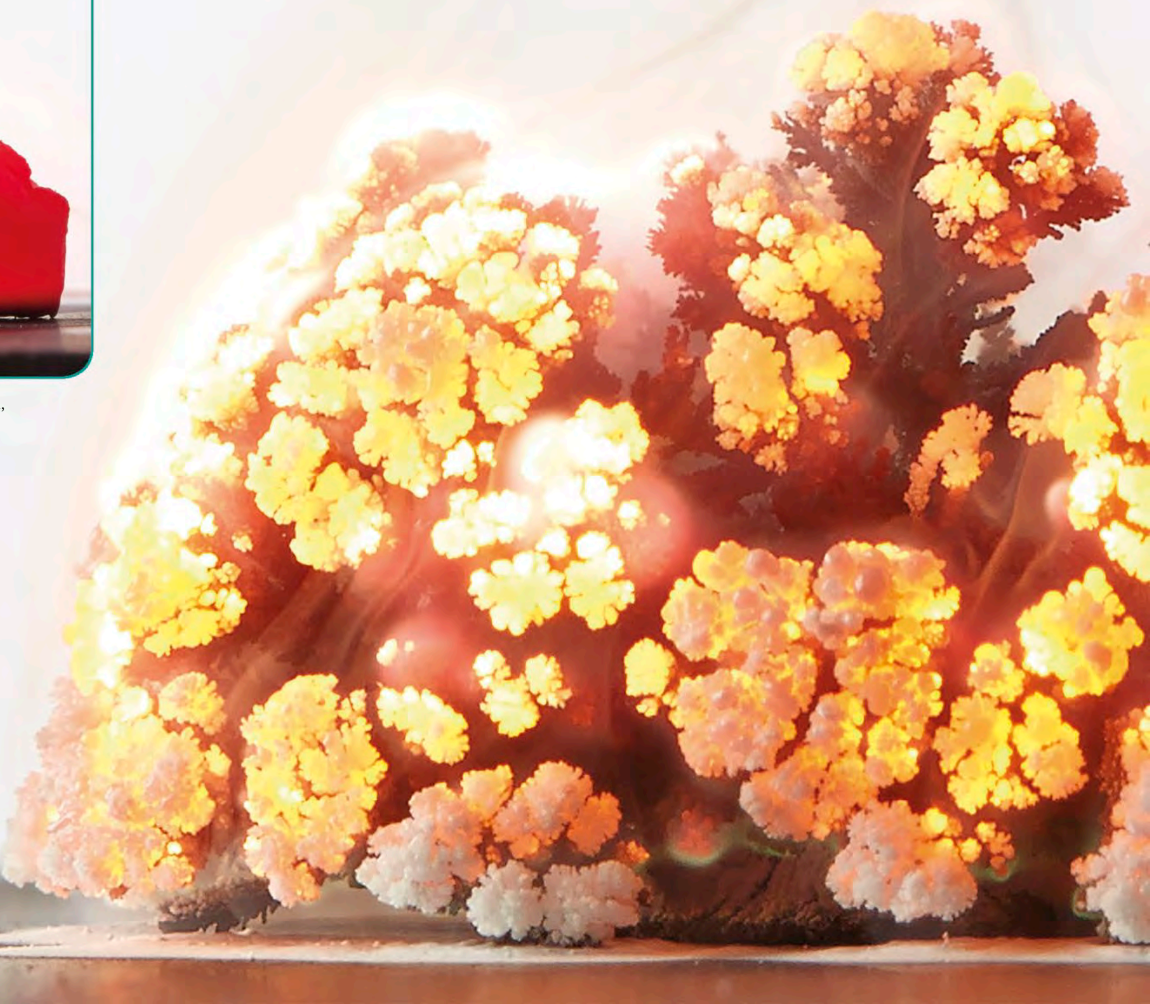
Reactions and uses

Explosive reaction
In this chemical reaction, pure lithium reacts with air to make the compound lithium oxide. It takes energy to break the links between the lithium atoms and then make bonds with oxygen in the air. Reactions need energy to begin, but they often produce energy as heat and light.

The elements can combine in different ways to make 10 million compounds, possibly more. As well as learning about the physical and chemical properties of elements, chemists also want to find out how and why certain elements react with each other to form compounds. Chemical reactions are happening all the time. During a reaction, substances change into new substances. The bonds that hold them are broken and then remade in a different combination.

1. This piece of pure lithium is placed on a surface and is exposed to the air.

2. A gas torch is used to heat the lithium, and in just a few seconds it turns red, which is a typical colour for this metal when it becomes hot.

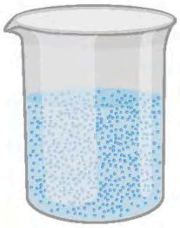


3. Very quickly, the lithium catches fire. The white areas forming here are the compound lithium oxide, which is a combintion of lithium and oxygen.

Mixtures

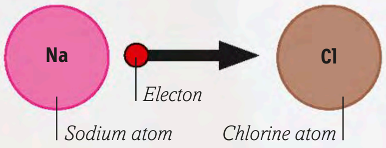
A mixture is a combination of substances that can be separated by physical means, such as filtering. It is not the same as a compound, where the ingredients are connected by bonds and can only be separated using a chemical reaction. Mixtures can be classified as solutions, colloids, and suspensions.

Solution
In this mixture, a substance is completely and evenly mixed, or dissolved, into another substance. Seawater is a solution.



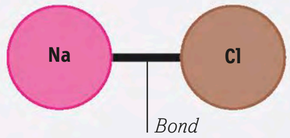
Colloid
This mixture contains unevenly spread particles and clusters that are too small to see. Milk is a colloid.

Suspension
This type of mixture consists of large particles of one substance floating in another substance. Muddy water is a suspension.



1. A sodium atom donates one electron to a chlorine atom. This gives both atoms full outer electron shells.

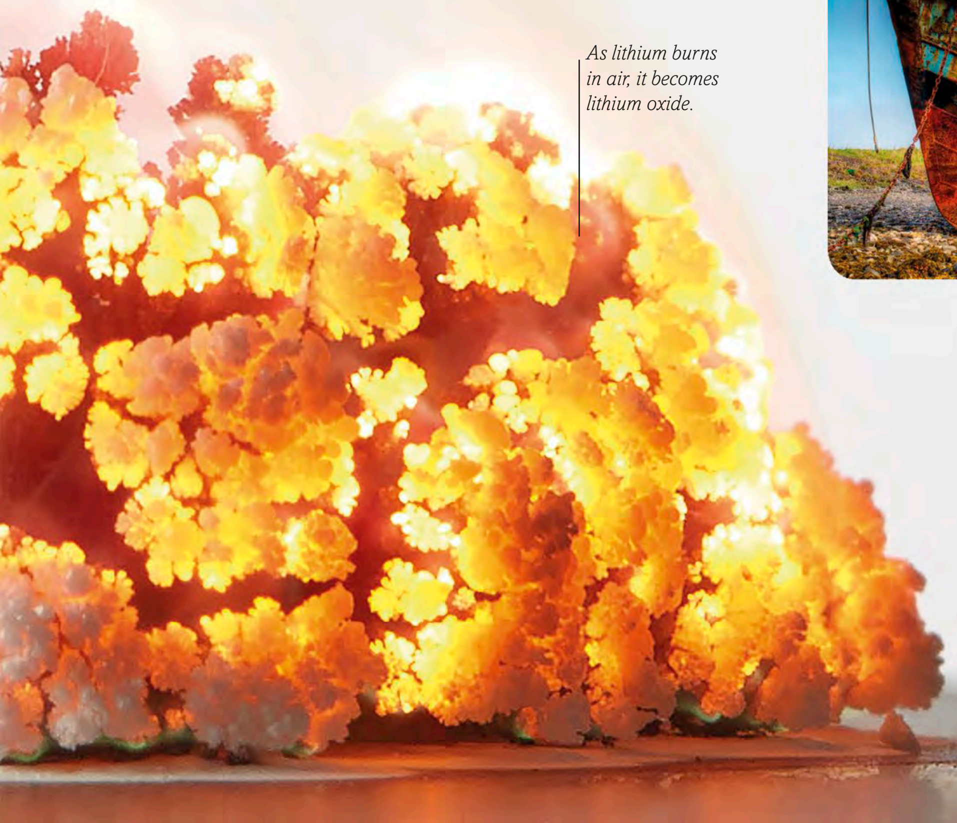
2. These are now charged atoms known as ions. The sodium ion has a positive charge and the chlorine ion has a negative charge.



3. Sodium is attracted to – and forms a bond with – chlorine, forming a molecule of the compound sodium chloride.

Forming compounds

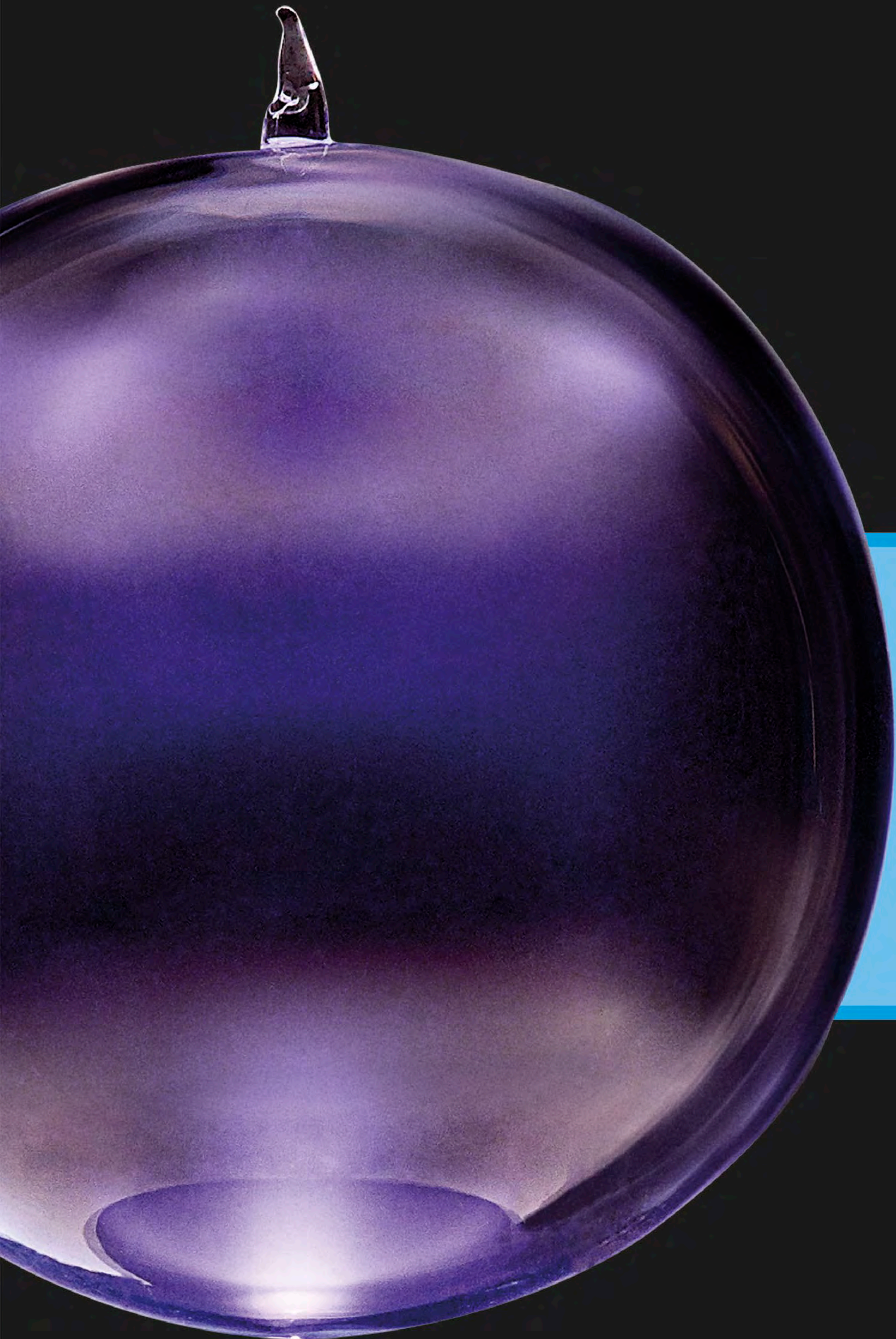
There are two kinds of bonds formed between elements during a chemical reaction. In an ionic bond, such as in sodium chloride (above), one atom gives away its electron(s) and another accepts them. This results in each having full outer electron shells. The other type is called covalent bonding. In this, atoms sit together and share their electrons so they both have full outer shells.



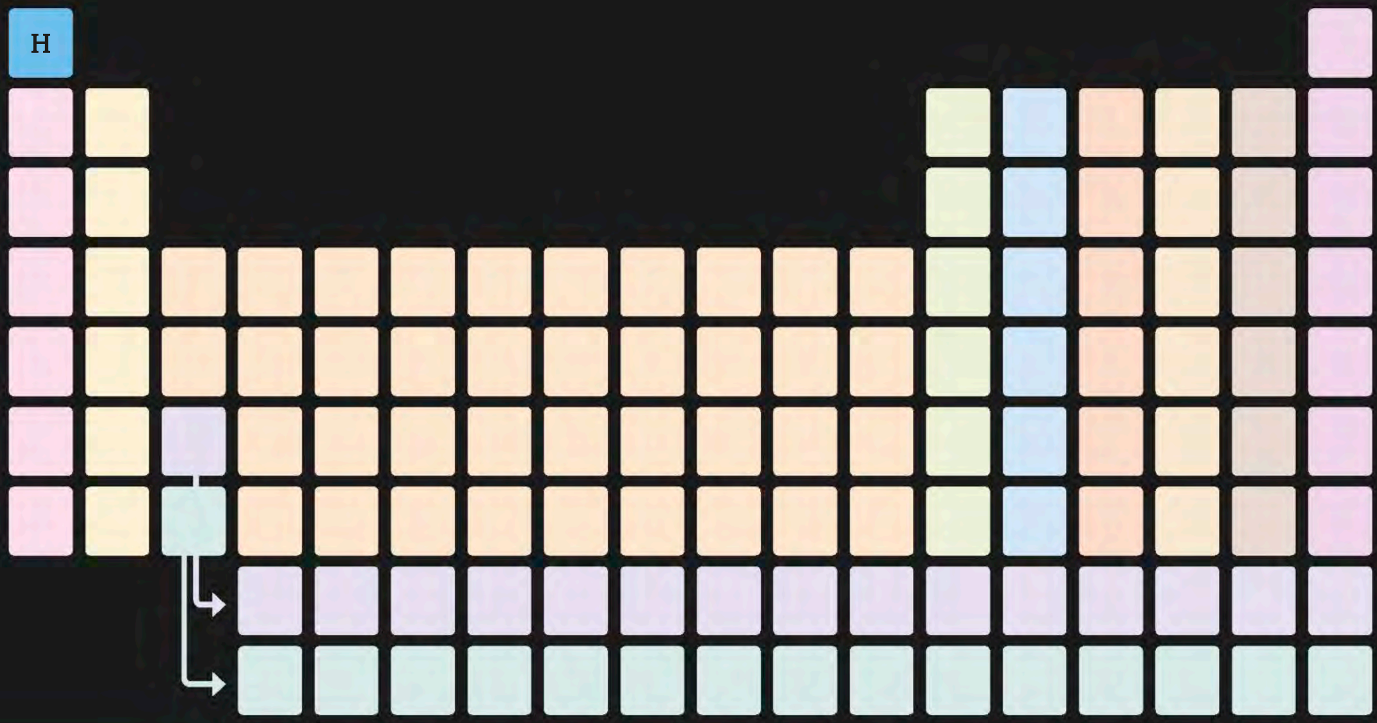
As lithium burns in air, it becomes lithium oxide.

Reactions in the real world

Chemical reactions happen all around us. There are reactions when we cook, take medication, or breathe. The image above shows a rusty iron ship. Over time, the element iron develops this red, flaky layer when it reacts with oxygen present in water or air to form the compound iron oxide – more commonly known as rust.



Pure hydrogen (H) fills this glass sphere, and produces a purple glow when electrified.



Hydrogen

The first element, hydrogen (H), is located above the alkali metals in the first column of the periodic table. However, because it is so different to the elements below it, hydrogen is not included in their group. This gas has the simplest atoms of any element with one electron and one proton. It is highly reactive and forms compounds with all kinds of other elements.

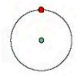
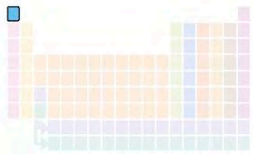
Atomic structure
A hydrogen (H) atom has one electron moving around a nucleus consisting of a single proton.

Physical properties
Hydrogen gas is the lightest material in the Universe. Pure hydrogen is rare on Earth, as it escapes quickly from the atmosphere into space.

Chemical properties
Hydrogen is highly flammable. It forms compounds with both metals and non-metals.

Compounds
The most common hydrogen compound is water. Acids are compounds that contain hydrogen.

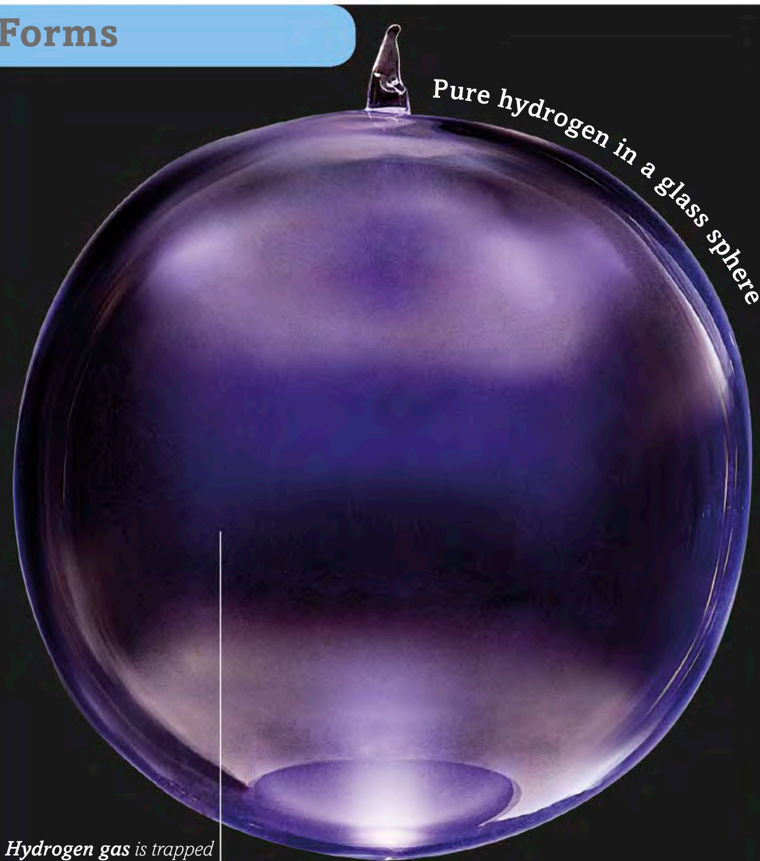
1
H
Hydrogen

$-$ 1 $+$ 1 0

State: Gas
Discovery: 1766

Forms



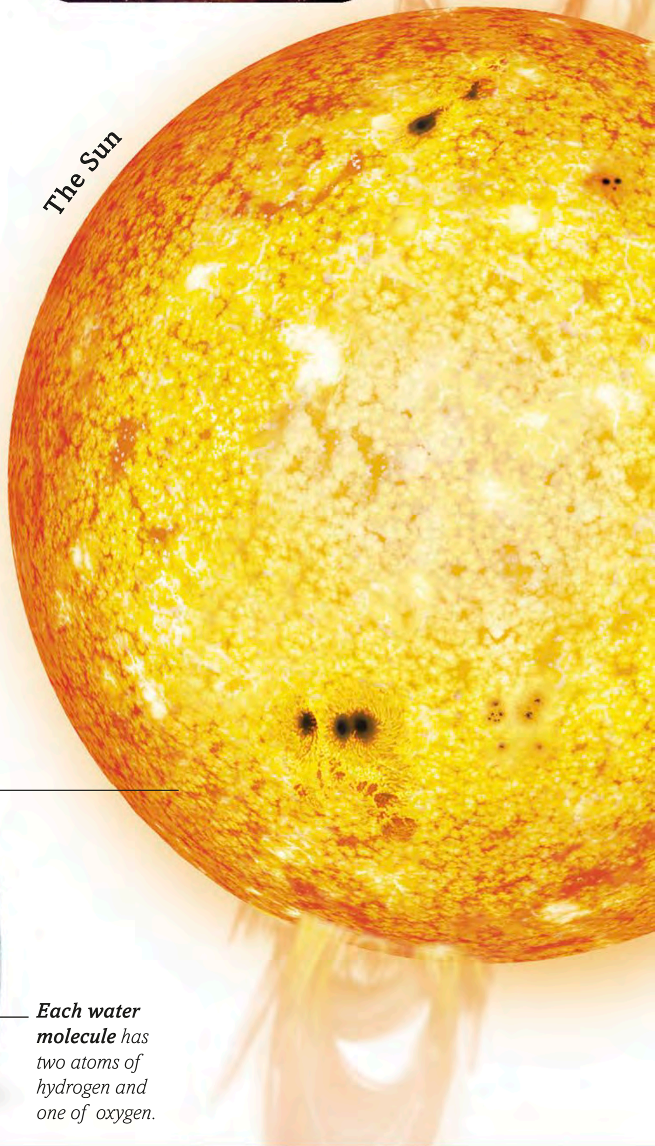
Pure hydrogen in a glass sphere

Hydrogen gas *is trapped inside this glass sphere, and gives off a purple glow when electrified.*

The Orion Nebula

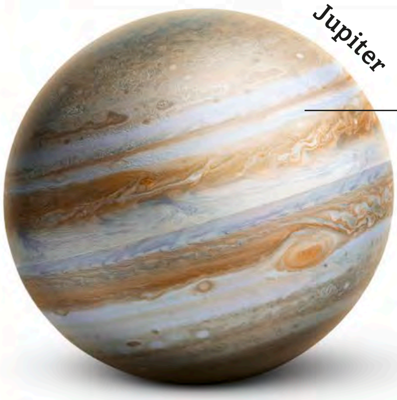
This gaseous stellar nursery *is giving birth to thousands of stars.*

The Sun



The Sun *is four-fifths hydrogen.*

Jupiter



Three quarters of this planet *is made up of layers of gaseous and liquid hydrogen.*

Water

Each water molecule *has two atoms of hydrogen and one of oxygen.*

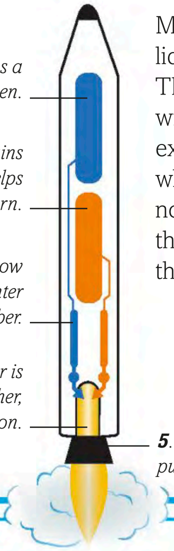
Hydrogen is the first member of the periodic table because it has the simplest atoms of all elements: they contain just one proton and one electron. Pure hydrogen is a transparent gas. The biggest planets, such as **Jupiter**, are vast balls of hydrogen mixed with other gases, such as helium and methane. On Earth, hydrogen is commonly found in **water**. Although it is rare in Earth's atmosphere, hydrogen is the most common element in the Universe. Stars, such as the **Sun**, contain large amounts of hydrogen. At the centre of a star, atoms of

Uses

Hydrogen-filled balloon

This balloon *can rise high into the atmosphere where sensors gather information about atmospheric pressure, temperature, and wind speed.*

HOW ROCKET FUEL WORKS



1. This chamber contains a fuel called liquid hydrogen.

2. This chamber contains liquid oxygen, which helps the hydrogen burn.

3. Pumps control the flow of the liquids as they enter the combustion chamber.

4. The combustion chamber is where the liquids mix together, creating an explosion.

5. The nozzle emits hot vapour, pushing the rocket upwards.

Many space rockets use liquid hydrogen as a fuel. The hydrogen reacts with oxygen to form extremely hot steam, which blasts out of the nozzle. This creates thrust, which pushes the rocket upwards.

Delta IV rocket

This powerful rocket *uses 45,460 litres (12,000 gal) of liquid hydrogen as fuel.*

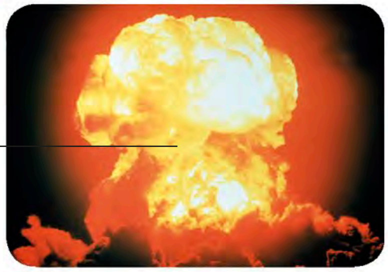
Margarine

Margarine *is made of vegetable oils thickened by adding hydrogen.*

Hydrogen peroxide

This liquid *is used as a cleaner.*

The only **waste product** of hydrogen fuel is **steam**.



This powerful explosion was *created by fusing hydrogen atoms.*

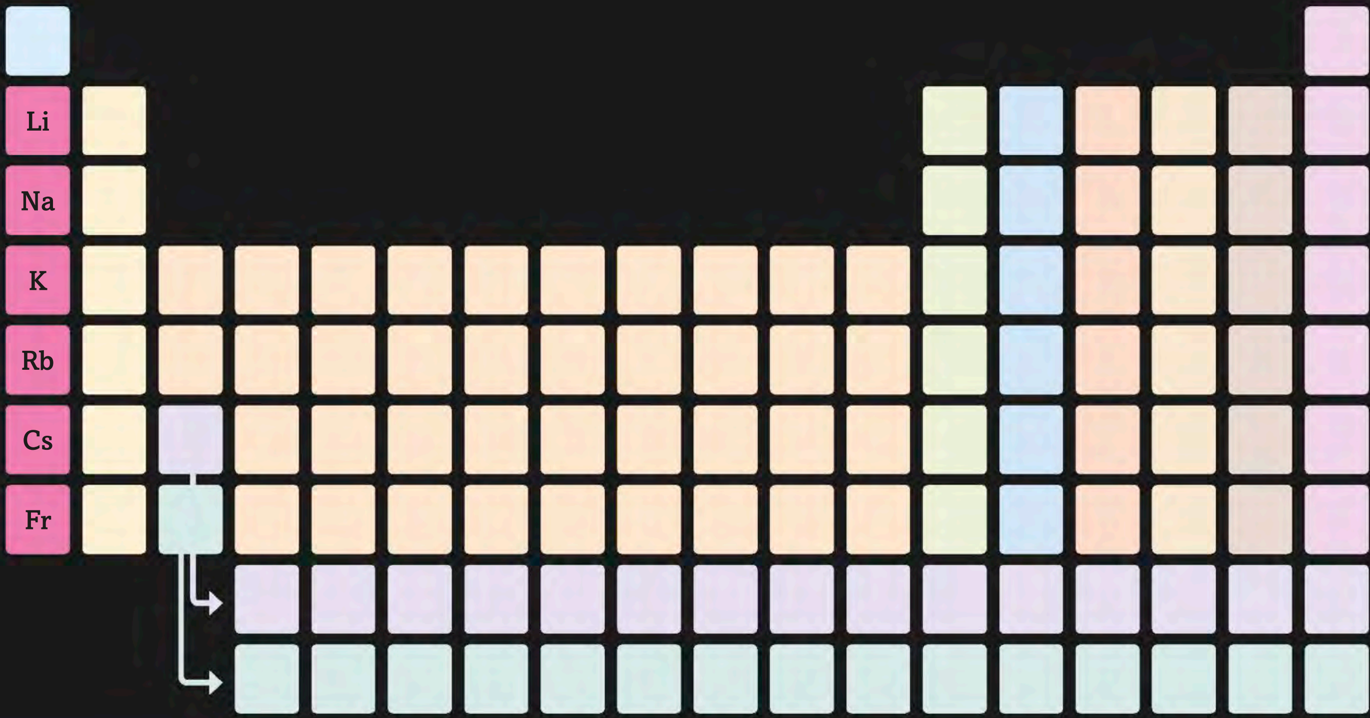
Hydrogen bomb explosion

This energy-efficient bus *runs on a fuel cell fed by hydrogen.*

Hydrogen-powered bus

this element are fused together, releasing heat and light. New stars form inside **nebulae** – such as the **Orion Nebula**. They are clouds of hydrogen gas that slowly collapse in on themselves. Hydrogen gas is the lightest element of all, and much lighter than air. This is why **hydrogen-filled balloons** can fly higher than air-filled ones. Supercold liquid hydrogen is used as **rocket** fuel. Atoms of hydrogen fuse together to produce a lot of energy in **hydrogen bomb** explosions. Pure hydrogen is also a clean energy source used to power some **buses** and cars.

Potassium (K) tarnishes when exposed to air.



Alkali Metals

After hydrogen (H) – which is in a group of its own – the first column of the periodic table contains the alkali metals. This group gets its name from the way the elements react with water. These vigorous reactions always produce acid-attacking compounds called alkalis. None of the alkali metals are ever found in a pure form in nature. The first three metals are common in many minerals, while the last three are rarer.

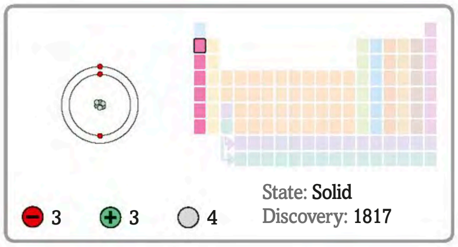
Atomic structure
The atoms of all alkali metals have just one electron in their outer shell. Alkali metal atoms are among the biggest of all atoms.

Physical properties
These metals are soft enough to be cut with a knife. They are all silvery and very shiny when clean.

Chemical properties
Alkali metals are highly reactive. They form bonds with other elements, giving away their single outer electron.

Compounds
These metals react with water to form compounds called hydroxides. They react easily with halogens to form salts, such as sodium chloride.

3 Li Lithium



Forms

Drinking water

***This water** contains tiny amounts of dissolved lithium minerals.*

Oyster mushrooms

***These mushrooms** absorb lithium from the soil.*

Lepidolite

Pale quartz

***Purple crystals** containing lithium*

Prawn

***Prawns** and other shellfish absorb lithium from seawater.*

Bar of pure lithium refined in a laboratory

***Shiny pure lithium** becomes dull when it is exposed to air.*

Petalite

Grey-white crystals

Lithium is the the lightest of all metals: in fact, it can easily float on water. Pure lithium is very reactive and exists in nature only in minerals, such as **lepidolite** and **petalite**. Many lithium minerals dissolve well in **water**, and the world's seawater contains millions of tonnes of dissolved lithium. Lithium is found in many foods, such as **mushrooms**, **prawns**, nuts, and seeds. It also has many everyday applications. Glass composed of lithium is resistant to heat and is used in scientific equipment, such as **mirrors inside**

Uses

***Smartphones** run on rechargeable batteries that use lithium to store electricity.*

Smartphone

Hale telescope mirror

***Lithium added to the glass in this mirror** stops the disc warping at extreme temperatures.*

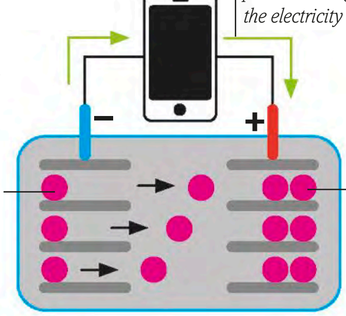
LITHIUM-ION BATTERY

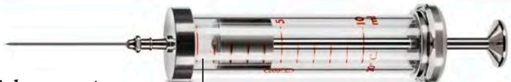
Lithium-ion batteries are widely used in digital devices. They store electrical energy to power gadgets and are rechargeable. This diagram shows a device's battery in use; when it is charging, this process is reversed.

1. Inside the battery, positively charged lithium ions move from the negative electrode (-) to the positive electrode (+).

2. The positive electrode receives lithium ions as the battery loses charge.

3. As ions move inside the battery, negatively charged electrons are pushed through the phone, providing the electricity to make it work.





Syringe

***Lithium coating on the inside of some syringes** delays the clotting of the blood sample.*

***Lithium-rich grease** is used to keep mechanical parts of engines running smoothly, even when hot.*

Grease

***Some artificial teeth** contain lithium disclate, which makes them strong.*

Artificial teeth

This car runs for at least **64 km** (40 miles) on one charge of its lithium-ion battery.

***This charging point** can recharge an electric car in one hour.*

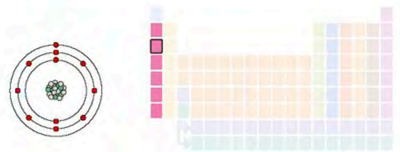
Electric car

***This air scrubber** used lithium hydroxide to purify the air inside the Apollo 13 spacecraft.*

Air scrubber

telescopes. The main use for lithium is in rechargeable batteries. Lithium-ion batteries are small but powerful, so they are ideal for **smartphones** and tablet computers. Larger lithium batteries can power **electric cars**, which are less polluting than petrol-powered ones. A soapy compound called lithium stearate is used to make **grease**, which helps automobile engines run smoothly. This element also forms hard ceramics that are used to produce strong **artificial teeth**. Lithium compounds are used in some medicines as well.

11 Na Sodium



State: Solid
Discovery: 1807

11 11 12

Forms

Clinoptilolite

This sodium-rich mineral is an example of a zeolite, a mineral with tiny holes that can trap gases.

Pure halite crystals

Cube-shaped transparent crystals

Laboratory sample of pure sodium in an airless vial

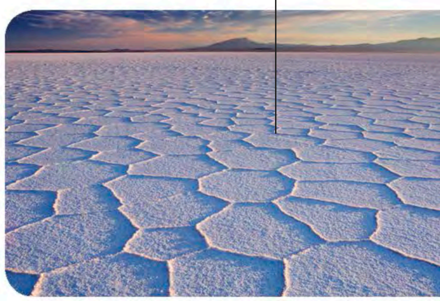
Soft, shiny metal

This glass case holding pure sodium has no air in it, to prevent the metal from reacting with oxygen in air.

Sodalite cabochon

Polished gemstone made of the mineral sodalite

The thick, white crust covering this salt flat contains sodium chloride and other salts.



Salar de Uyuni, Bolivia

Everyday salt contains lots of sodium. Although abundant on Earth, sodium is never found in its pure form naturally: it forms compounds with other elements. Sodium chloride, which also contains chlorine, is the most common sodium compound. It is also known as the mineral **halite**, and it is what makes seawater salty. Other sodium minerals include **sodalite**, a soft blue stone that can be shaped and polished. **Pure sodium** is soft enough to be cut with a knife. It reacts with oxygen in the air, forming a compound called sodium oxide, and bursts

Uses

Common salt

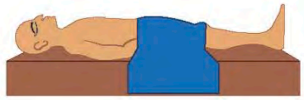
Edible salt *is made by refining the mineral halite.*

Mummy

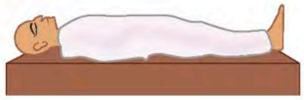
This mummified body*, or mummy, was preserved using sodium compounds.*

MUMMIFICATION

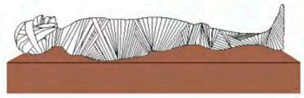
Ancient Egyptians believed in life after death and so preserved the bodies of their dead. A dead body was washed and the organs removed, then crystals of sodium compounds were used to dry it out. Finally, the body was wrapped, which completed the process of mummification.



1*. Organs, such as the stomach and lungs, were removed from the dead body.*



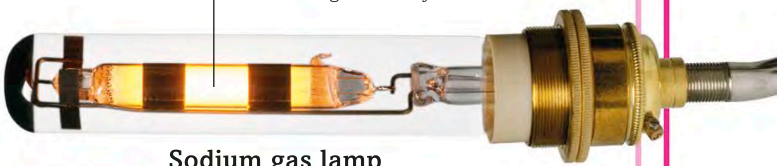
2*. Sodium compounds were spread over the body to dry it.*



3*. The body was wrapped in cloth to mummify it.*

Sodium fireworks

Bright yellow lights in fireworks *get their colour from burning sodium compounds.*



This tube *glows bright yellow-orange when sodium gas is electrified.*

Sodium gas lamp

Cats were sacred in ancient Egypt, so their bodies were mummified.

Bar of soap

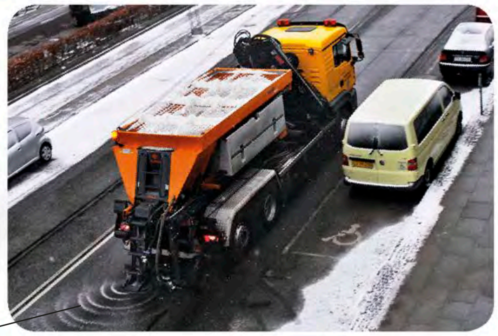
Some soaps *contain sodium hydroxide.*

Baking soda

Odourless white powder

Indigo dyes *– often used in blue jeans – contain sodium.*

Indigo dye powder



De-icing

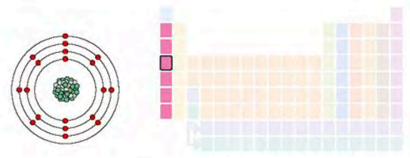
Spraying salt *keeps roads free from ice and frost.*

into flames when in contact with water. Sodium compounds in **fireworks** burn with a yellow-orange colour. In ancient Egypt, crystals of sodium compounds were used to preserve dead bodies as **mummies**. Another useful compound is sodium bicarbonate, or **baking soda**, which makes dough rise by releasing bubbles of carbon dioxide. When refined, sodium chloride, or **common salt**, has several uses. It makes ice melt so it is used in salty grit added to slippery, frozen roads. This helps **de-ice** them to make them safer. It is also an important seasoning for meals.

SALT FLATS Hundreds of artificial ponds dot the hillside near the small town of Maras, high in the Andes of Peru. The ponds fill with water from a stream that runs down from the nearby mountains. In the sunshine, the water evaporates, leaving behind a thick salt crust that can be collected. The people of Maras have been gathering salt in this way for at least 500 years.

The salt forms part of rocks deep underground before it is dissolved by the stream and flows into the pools. Evaporation can also be used to collect salt from seawater or other salty water sources (known as brines). Today, however, most of the world's salt comes from underground mines containing thick layers of salt that are a result of ancient seas drying out. Over millions of years, that dry salt has become buried under dense layers of rocks. This so-called "rock salt" is sometimes unearthed using excavators. At other mines, it is washed out by piping in warm water, which dissolves the salt. The brine is then pumped up to the surface for evaporation.

19
K
Potassium



19 19 20

State: Solid
Discovery: 1807

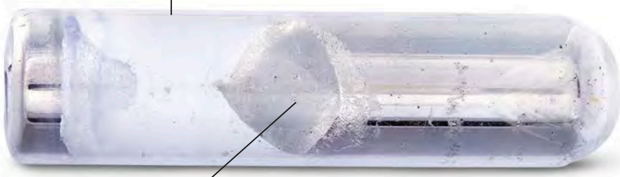
Forms

This mineral *is rich in potassium chloride.*

Potash

This glass case holding pure potassium *has no air in it, preventing the metal from reacting with oxygen in air.*

Laboratory sample of pure potassium in an airless vial



Soft and shiny solid

The yellow and green colour *comes from impurities.*

This mineral *contains potassium chloride, which gives it a salty taste.*

Sylvite

Potassium was first found in the dust of burnt plants. It was discovered by Sir Humphry Davy when he experimented with **potash** – a mixture of substances made from the ash of burnt plants soaked in water. The name potassium comes from potash but the element's chemical symbol, K, is taken from *kalium*, a Latin word for "ash". Potassium is never found pure in nature, but is present in minerals such as **aphthitalite** and **sylvite**. Potassium is vital for the human body, helping muscles and nerves work properly. For this, we rely on

Aphthitalite

Uses

Soda water

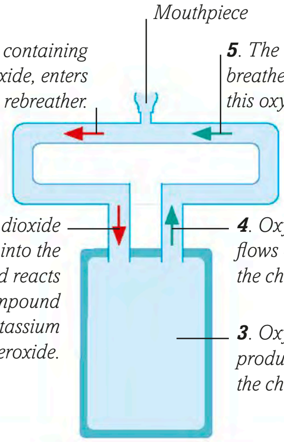
Soda water *contains potassium compounds for added flavour.*

Potassium salt

***This salt** contains potassium chloride, which helps lower blood pressure.*

REBREATHER

A rebreather is a machine used by expert divers so they can stay underwater for long periods.



Rebreather

***This cylinder** contains a compound called potassium superoxide.*

***Potassium solutions** are used to hydrate patients.*

Saline drip

***Potassium-rich fertilizer** is easily absorbed by the soil and boosts plant growth.*

Fertilizer

Potassium-rich food

Banana

Avocado

Sweet potato

Gunpowder

***This explosive mixture** contains powdered potassium nitrate.*

Liquid soap

***This soap** contains potassium hydroxide, which is a cleaning agent.*

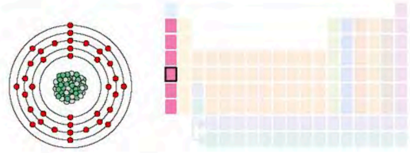
Toughened glass screen

***This strengthened glass sheet** contains potassium nitrate.*

potassium-rich food, such as bananas, root vegetables, and avocados, which contain potassium chloride. In tiny amounts, this compound can enhance flavours, as it does in **soda water**. It is also a healthy alternative to sodium chloride, or common salt, and an important ingredient in **saline drips** for rehydrating patients who are seriously ill. Potassium nitrate is a compound of potassium, oxygen, and nitrogen, and is found in **gunpowder** and **toughened glass screens** for mobile phones.

37
Rb

Rubidium



37 37 48
State: Solid
Discovery: 1861

Forms

Laboratory sample of pure rubidium in an airless vial

This glass case contains ***pure rubidium****, preventing it from coming into contact with air and catching fire.*

Leucite

Pale, waxy mineral

Lepidolite

This soft mineral *contains up to 3.5% rubidium.*

Pollucite

Rubidium makes up only about **1 per cent** of this mineral.

This ore *contains caesium and rubidium.*

Rubidium was named after the Latin word *rubidius*, meaning "deepest red". This refers to the red-coloured flame it produces when burned. This highly reactive element ignites on contact with air. On contact with water, it reacts vigorously, producing hydrogen gas and a lot of heat. Rubidium is not often concentrated in particular minerals, but instead is spread in small amounts through a wide range of minerals, such as **leucite** and **pollucite**. The pure metal is sourced mainly from the mineral **lepidolite**. Another mineral called rubicline has even more

Uses

These lenses contain rubidium, which aids night vision.

Night-vision goggles

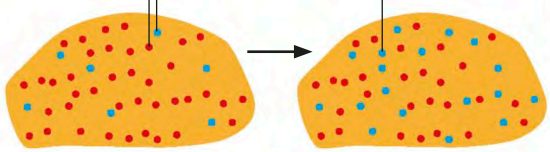
RUBIDIUM-STRONTIUM DATING

About a quarter of all rubidium atoms are radioactive. Slowly over time, they break down into strontium atoms. Comparing the amounts of these elements in a rock shows when that mineral was formed. Older rocks have less rubidium and more strontium in them.

Rubidium-87 atoms (red) decay at a predictable rate.

Only small amounts of strontium-87 (blue) in the rock.

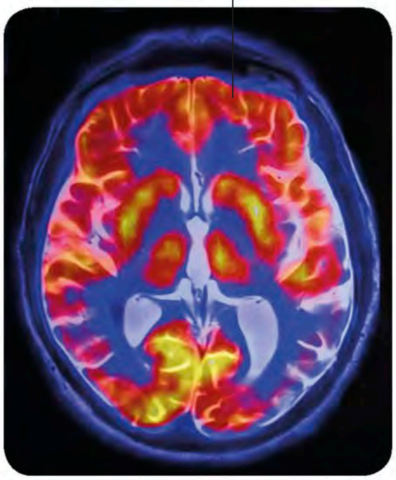
The amount of strontium-87 has increased over time.



Millions of years ago

Present day

The structure of the brain *can be seen clearly because of the use of radioactive rubidium.*



PET scan

This sensitive device *detects light by using a rubidium compound.*

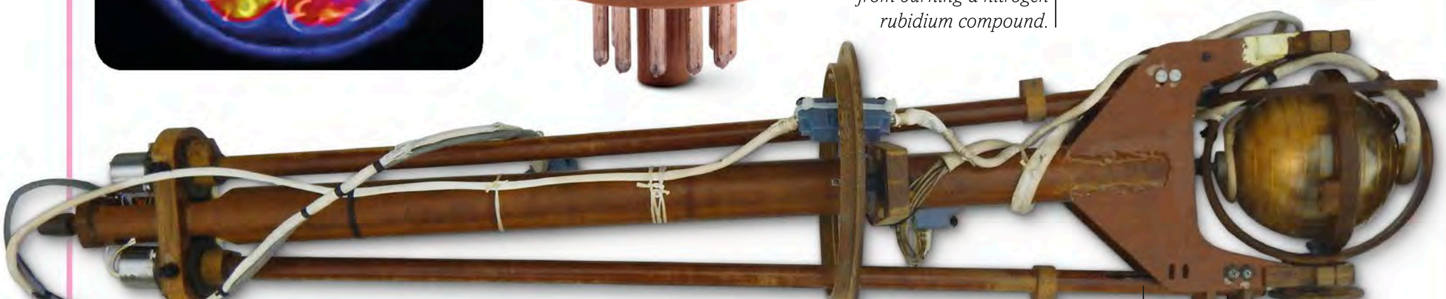
Photomultiplier

Fireworks

This purple colour *comes from burning a nitrogen rubidium compound.*

Electricity cables *are hung from these rubidium-rich insulators.*

Ceramic insulator



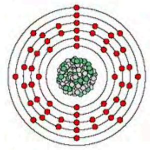
Magnetometer

This device *from the early 20th century used rubidium to measure the strength of magnetic fields.*

rubidium in it but is very rare. Rubidium atoms are sensitive to light and can be used in photoelectric cells (devices that convert light energy into electricity) and **night-vision equipment**. This element has radioactive forms, which can be used to measure the age of rocks. When injected into a patient's body, rubidium targets tumours, which show up clearly on **PET (positron emission tomography) scans**. Rubidium is also used by light-sensitive electronics called **photomultipliers**, and in making **insulators** for high-voltage cables and some special types of glass.

Alkali Metals

55
Cs
Caesium



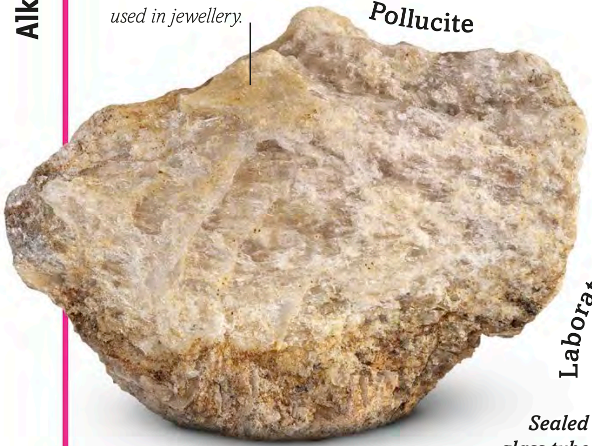
55 (electrons) 55 (protons) 78 (neutrons)

State: **Solid**
Discovery: **1860**

Forms

__The crystals of this mineral__ are used in jewellery.

Pollucite



__Shiny, silver-gold metal__

Laboratory sample of pure caesium in an airless vial

__Sealed glass tube__

KIRCHHOFF AND BUNSEN

Caesium was discovered in 1860 by German scientists Robert Bunsen and Gustav Kirchhoff. They burned a sample of mineral water on a burner, which split the flame's light into individual colours. One of them was a distinctive light blue, which came from caesium.

Gustav Kirchhoff (left) and Robert Bunsen (right)

Uses

__This highly accurate clock__ is also called a caesium clock.

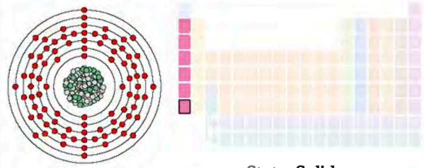
Atomic clock

Drilling fluid

__High-density caesium compounds__ in this fluid stop toxic gases rising to the surface.

As the most reactive metal on Earth, caesium explodes into flames if in contact with air or water. Therefore, **pure caesium**, is stored in a sealed glass tube from which all the air has been sucked out. This element is rare, and most of it is extracted from the mineral **pollucite**. Its name means "sky blue" and refers to the colour of caesium's flame when burning. Caesium is used in **atomic clocks**, which measure time down to a billionth of a second. These clocks are so accurate that they would gain or lose no more than one second every 300 years.

87
Fr
Francium



87 87 136

State: Solid
Discovery: 1939

Thorite

***This mineral** was discovered in 1828 in Norway.*

MARGUERITE PEREY

The French chemist Marguerite Perey discovered francium in 1939 while studying the way a pure sample of another radioactive metal – actinium – decayed. She found that actinium broke down to form thorium and a previously unknown element. She named this element francium after her home country.

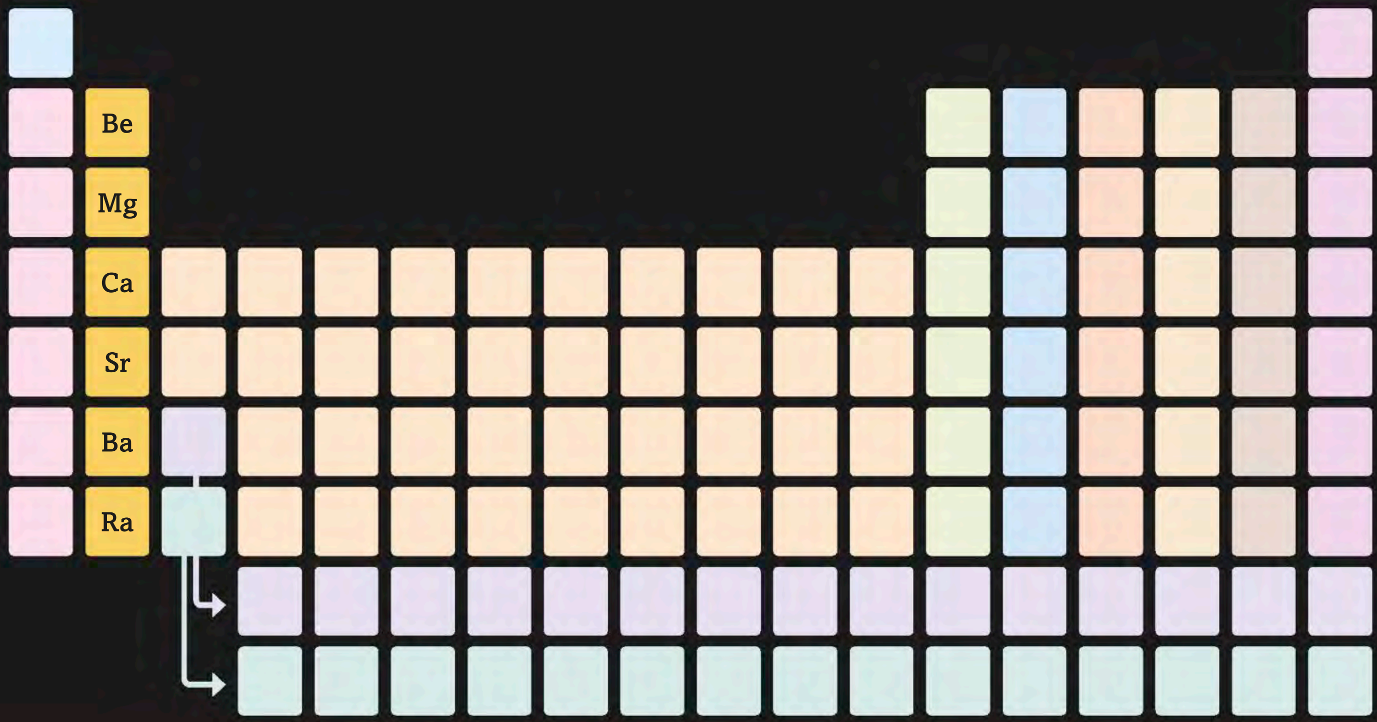
***The dark crust** is a uranium mineral that holds tiny amounts of francium.*

Earth's rocks have **one** francium **atom** for every million trillion uranium atoms.

Uraninite

Francium is the rarest natural element on Earth. Scientists think there may be just 30 g (1.1 oz) of francium in Earth's rocks. Francium atoms are created when radioactive elements break down. Francium can be extracted from radioactive ores such as **thorite** and **uraninite**, both of which contain tiny amounts of this element. Even so, to date the largest sample of the metal made contained only 300,000 atoms, and lasted only a few days. Francium has no known uses outside of research.

Barium (Ba) crystals turn black in air.



Alkaline Earth Metals

This group is a collection of reactive metals that were discovered as compounds inside common minerals in Earth's crust. Most of these minerals – known in the past as "earths" – are alkaline (alkali-producing), and this is how the group got its name. All alkaline earth metals were first purified in the 19th century.

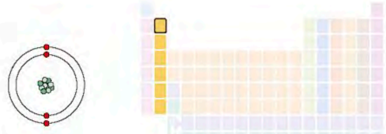
Atomic structure
The alkaline earth metals have two electrons in their outermost electron shell. Radium (Ra) is the most radioactive member.

Physical properties
All members of this group are soft and shiny when pure. They are solid at room temperature.

Chemical properties
These metals are similar to the alkali metals, but not as reactive. Except for beryllium (Be), all alkaline earth metals react with hot water or steam.

Compounds
These elements form compounds with non-metals by losing their outermost electrons. Several compounds are found in teeth and bones.

4 Be Beryllium



4 4 5

State: Solid
Discovery: 1797

Forms

This mineral can also be brown, green, or orange.

Chrysoberyl

Aquamarine

These crystals have this pale blue colour due to iron impurities.

Laboratory sample of pure beryllium

Lightweight metal

Beryllium is found in more than **30 kinds of mineral**.

This widely used element gets its name from the Greek word *beryllos*, after which the mineral beryl is also named. Beryllium is the lightest of the alkaline earth metals, but it does not share many of the group's properties. For example, it does not react with water and is much harder than the other metals in its group. Two common beryllium minerals are **chrysoberyl** and beryl. Beryl has different forms, such as **aquamarine** and emerald. Beryllium is useful in many ways. For example, some military **helicopters** use windows made

Uses

Apache attack helicopter

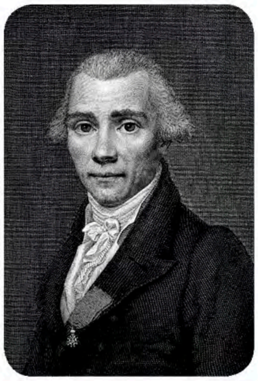
Beryllium alloy window

Fire sprinkler

***This seal** made of a beryllium-nickel alloy is strong enough to stop high-pressure water supply leaking through.*

LOUIS NICOLAS VAUQUELIN

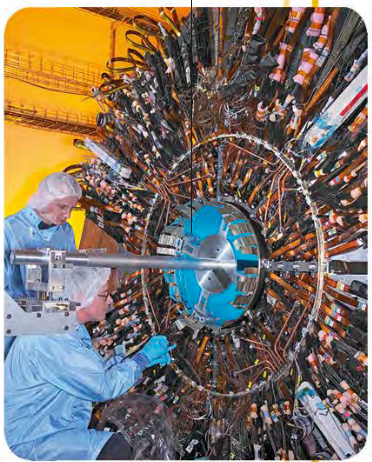
Beryllium was discovered in 1798 by the French chemist Louis Nicolas Vauquelin. He extracted the pure metal from emerald, which is a valuable green form of the mineral beryl. He had already discovered the element chromium, which is also found in emerald and gives it its green colour.



***These beryllium mirror segments** will not contract in the cold of space.*

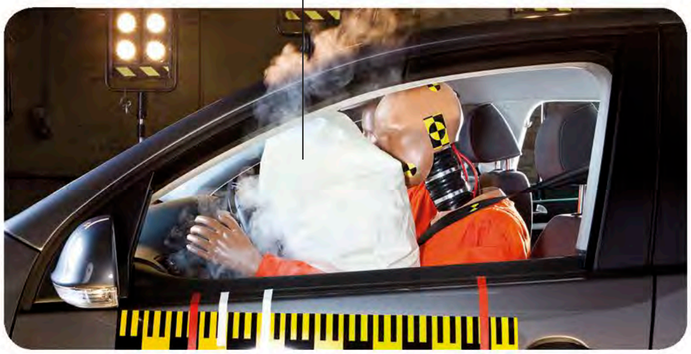
James Webb Space Telescope

***This beryllium pipe** delivers beams of protons into this device.*

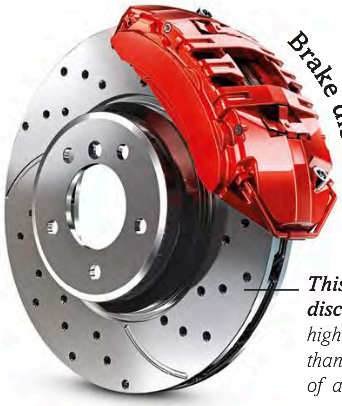


ATLAS, a device at the Large Hadron Collider, CERN, Switzerland

***This airbag** is triggered by a sensor that contains beryllium.*



Airbag

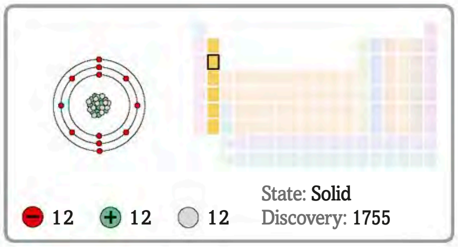


Brake disc

***This beryllium disc** can withstand higher temperatures than a disc made of aluminium.*

of beryllium-rich glass to shield optical sensors to aid pilots flying at night or through fog. Objects made of this metal keep their shape well and hardly expand or contract if the temperature changes. This makes beryllium useful in valves for **fire sprinklers** and car sensors that trigger **airbags**. NASA's **James Webb Space Telescope** will use a large beryllium mirror that is light and strong. Beryllium is also used to make **brake discs** for racing cars. Alloys of beryllium and copper are used in springs as well.

12 Mg Magnesium



Forms

Magnesium has **22 known isotopes**.

Magnesium was named after Magnesia in Greece. This element largely exists deep inside Earth's mantle, but it can also be found in seawater and many minerals in our planet's crust, including **serpentine**. Another mineral, **dolomite**, is also a source of **pure magnesium**.

Magnesium has many important applications. Alloys of magnesium are not only strong, but also lightweight, so are used in a range of objects, from **car wheels** to **cameras**. For centuries, many naturally occurring magnesium minerals have been used in traditional medicines.

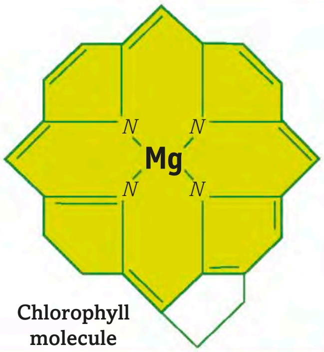
Uses

Alloy wheel

Magnesium alloy *makes this wheel strong and shiny.*

MAGNESIUM IN CHLOROPHYLL

Chlorophyll is an important molecule in plants and is what makes them green. At its centre sits a magnesium atom, which helps plants convert sunlight into energy in a process called photosynthesis.



Chlorophyll molecule

Digital camera

The magnesium alloy body *of this camera is lightweight and will not rust.*

Epsom salts

Crystals containing magnesium sulfate *are added to warm water for a soothing bath.*

This powder *makes skin smooth and soft.*

Talcum powder

This indigestion medicine *is a mixture of water and magnesium carbonate.*

Milk of magnesia

White lights *from burning magnesium compounds*

Magnesium fireworks

Portland cement

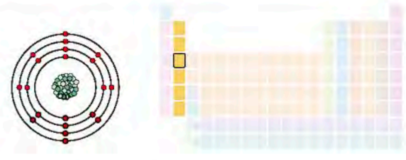
This widely used cement *contains powdered magnesium oxide.*

The magnesium alloy case *of this laptop is strong but lightweight.*

Laptop

Magnesium carbonate, or **magnesia**, reacts with acid in the stomach to settle indigestion. Heating magnesia produces magnesium oxide, which is one of the ingredients in **cement**. Magnesium compounds are also used in **fireworks**, and they burn hot with a white flame. Salts composed of magnesium, called **Epsom salts**, named after the place in England where they were first mined, work as a muscle relaxant. Magnesium silicate, known as **talc**, is a soft mineral used in body powders.

20
Ca
Calcium



20 20 20

State: Solid
Discovery: 1808

Forms

Calcite

Large, fang-like crystals

Aragonite

These column-shaped crystals contain calcium carbonate.

Bones are hardened by calcium phosphate.

Snake skeleton

This crystal has a shiny surface.

This pure metal is soft enough to cut with a knife.

Crystals of pure calcium refined in a laboratory

The most abundant metal in the human body, calcium is also the fifth most common element on Earth. It appears in many minerals: **calcite** and **aragonite** are made of a compound of calcium and carbon called calcium carbonate. Bones in animal **skeletons** contain the compound calcium phosphate. The hard, outer layers of many other animals, such as the **shells** of sea snails, are made of calcium carbonate. Calcium is very important in our diet. We get calcium by eating **calcium-rich food**, including dairy products, green

Shells of sea snails are hardened by calcium carbonate absorbed from sea water.

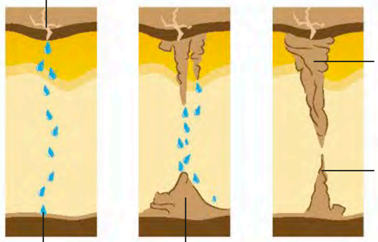
Uses

This tablet contains calcium carbonate, which is an alkali – a substance that balances out acids.

CALCIUM CAVES

As running water flows into caves, it deposits calcium carbonate. These deposits build up to form structures called stalactites and stalagmites.

Water with dissolved calcium carbonate flows through a crack and into the cave.



Stalactite hangs from the ceiling.

Stalagmite grows up from the ground.

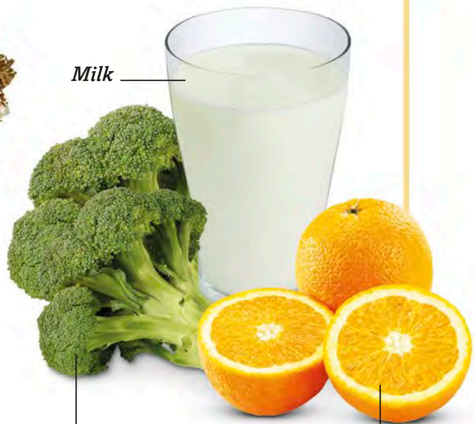
Water drips onto the ground.

Over time, calcium carbonate starts to build up on the ground and ceiling.

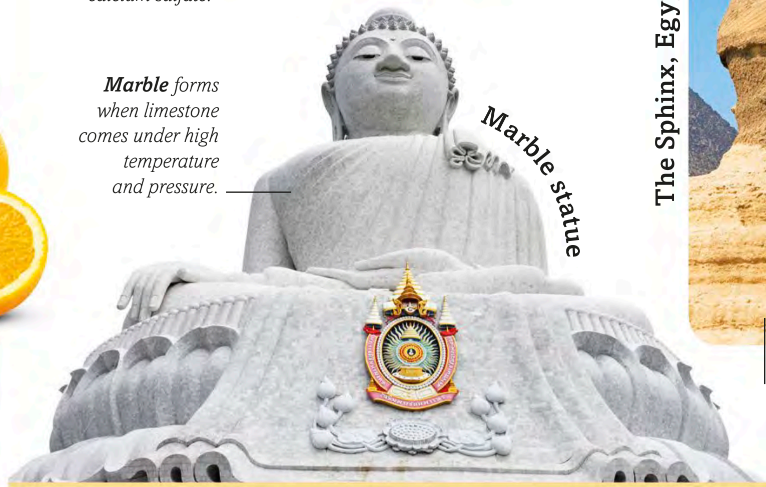
An adult **human** contains about **1 kg (2 lb) of calcium** in the body.

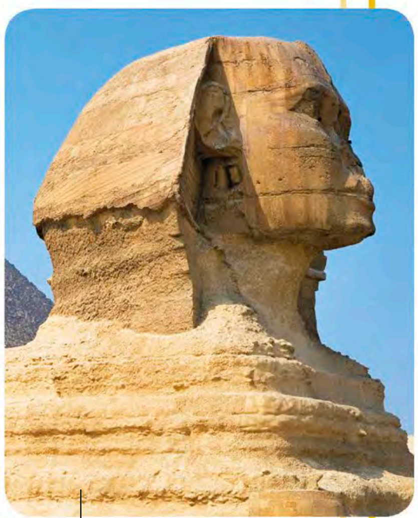
This plaster of Paris cast hardens when dry, supporting broken bones.

These chalks contain calcium sulfate.



Marble forms when limestone comes under high temperature and pressure.





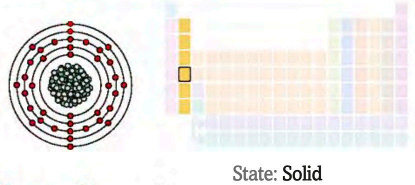
This statue is made of limestone, a natural rock containing calcium carbonate.

Oranges are also a good source of calcium, and most orange juices have extra calcium added to them. **Antacid tablets**, used to settle indigestion, contain calcium carbonate. This compound reacts with acid in the stomach. Calcium compounds are also common in construction materials. Plasterboard, which is used to make walls smooth, **writing chalk**, and **Plaster of Paris** are all made from the mineral gypsum. Calcium oxide is an important ingredient in cement and helps turn it into hard concrete.

FLY GEYSER The multicoloured Fly Geyser in the Black Rock Desert of Nevada, USA, is made from a mound of calcium carbonate rock. Such mounds and pools are made naturally in many other places where springs gush out warm, calcium-rich waters. The amazing colours of the rocks are caused by algae and bacteria that live in this water.

Fly Geyser is not a natural wonder. It was made by accident in 1964 when engineers were drilling a well to find a source of hot water. They did find a small reservoir of water that is heated by volcanic activity deep beneath the surface, but they chose to cap the well and look elsewhere. Eventually, the hot water broke through, creating a natural fountain, or geyser. Over the decades, the calcium deposits have slowly built up. The central mound is now 1.5 m (5 ft) tall and nearly 4 m (13 ft) wide. The scalding water that gushes out can reach a height of 1.5 m (5ft).

38
Sr
Strontium



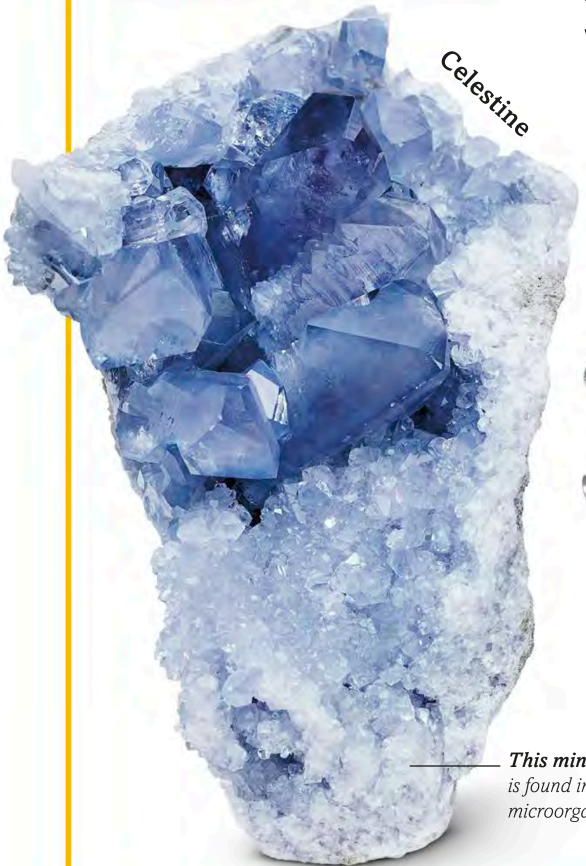
38 38 50
State: Solid
Discovery: 1790

Forms

Strontianite

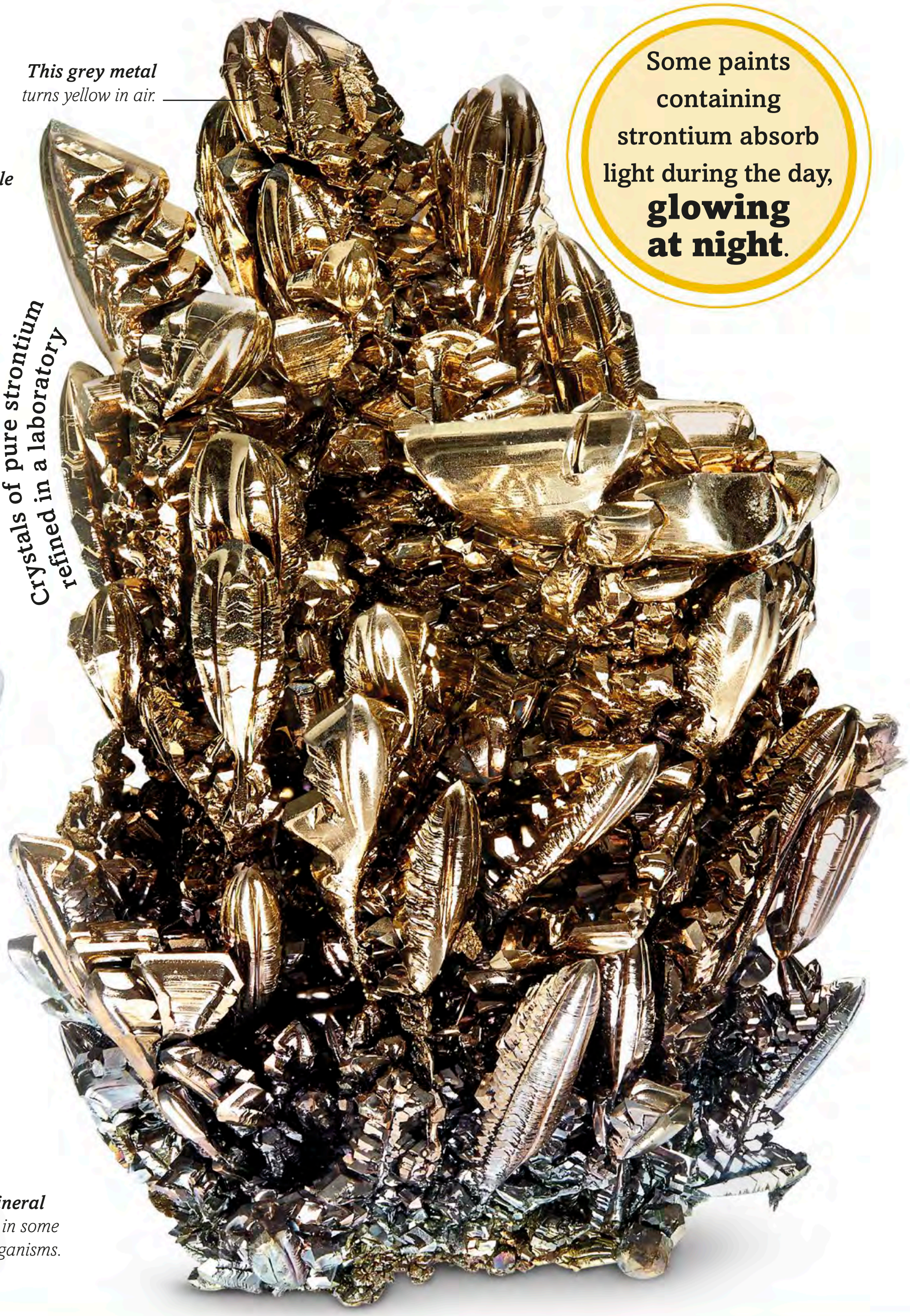
Soft, brittle crystals

Celestine



This mineral is found in some microorganisms.

Crystals of pure strontium refined in a laboratory



This grey metal turns yellow in air.

Some paints containing strontium absorb light during the day, **glowing at night**.

Strontium was discovered in 1791 in a mineral found near the Scottish village of Strontian. The mineral burned with a bright crimson flame, and Scottish chemist Thomas Charles Hope studied it and found that it contained a new element. This mineral was called **strontianite**, and it is the main ore of strontium. **Pure strontium** was first extracted by British chemist Humphry Davy in 1808, who conducted an experiment using electricity to obtain the element from the mineral. Strontium was once used in television screens, but today

Uses

Glazed ceramic

The bowl's smooth finish is due to strontium oxide.

Navigation buoy

Lights in unmanned buoys can be powered by radioactive strontium.

Loudspeaker

Magnets inside this loudspeaker contain strontium.

Strontium burns in air with a bright red colour.

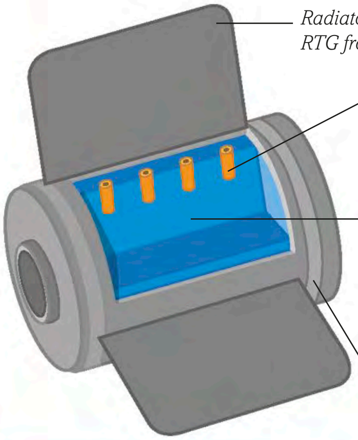
Flare

Strontium compounds in some toothpastes provide relief from pain.

Toothpaste for sensitive teeth

GENERATING ELECTRICITY

A radioactive form of strontium, called an isotope, can be used to produce electricity. A radioisotopic thermoelectrical generator (RTG) converts heat from the element into electricity for use in spacecraft.



Radiator fin prevents the RTG from overheating.

A thermocouple is a device that converts heat from the radioactive metal into electricity.

Inside the capsule, atoms of radioactive strontium break down into those of lighter elements and produce heat.

RTG is insulated to stop radioactivity from leaking out.

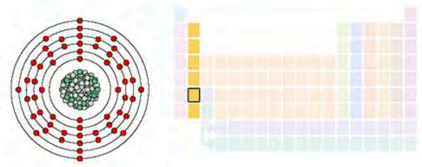
Unmanned radar stations run on electricity produced using a form of strontium called strontium-90.

Weather radar station

there are fewer uses for it. Strontium oxide in pottery and **ceramic** glazes creates distinctive colours, while strontium carbonate produces a red colour in **flares** and fireworks. Magnets that contain iron oxide can be made stronger by adding strontium to them. These strong magnets are used in **loudspeakers** and microwave ovens. Strontium chloride is added to some kinds of **toothpaste**, while radioactive strontium is a source of electricity for **radar stations** in remote places where there are no power lines or fuel supplies.

56
Ba

Barium



56 56 81
State: Solid
Discovery: 1808

Forms

Farmers used witherite as **rat poison** until the 18th century.

This mineral is used to make ceramic glazes.

Witherite

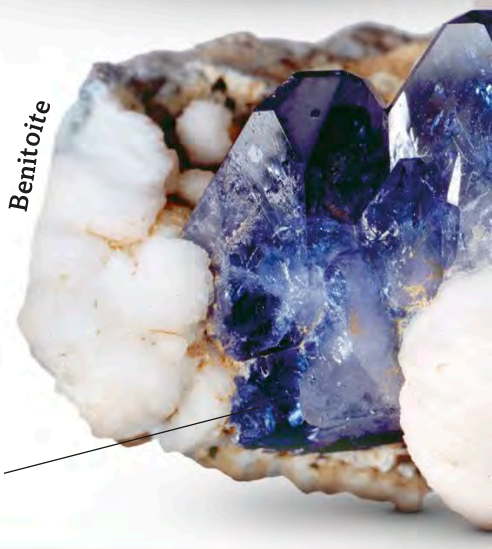
This soft metal has a light, golden shine.

A grey layer of tarnish forms when the metal comes into contact with air.

Desert rose

Petal-like shapes form in the desert when sand mixes with barite or with gypsum.

Benitoite

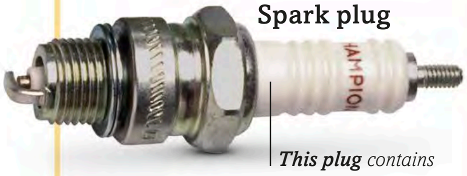


These glassy, blue crystals contain barium and titanium.

Barium is named after the Greek word *barys*, which means "heavy", because barium and its minerals are dense. The **pure form** of this element was first discovered in 1808 by the English chemist Humphry Davy, who extracted it from an oxide of barium. This does not exist in nature. Davy obtained it by heating the mineral **witherite**. Today, the main source of barium is barite, a mineral of sulfur that forms in deserts and in rock deposits that come into contact with hot water. A rarer mineral called **benitoite** also contains barium. The

Laboratory sample of pure barium crystals

Uses



Spark plug

This plug *contains an alloy of barium and nickel.*

Glass-making

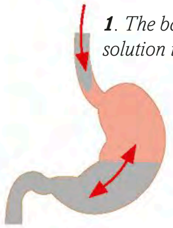
This glass *can be made shinier by adding barium oxide and barium carbonate.*

Jasperware pot

This pot *is made from clay that is rich in barium.*

BARIUM SOLUTION

Barium is used in a medical test for checking a patient's digestive tract for problems. In this test, a patient swallows a barium liquid solution, which fills the organs in the digestive tract.



1. *The barium solution is ingested.*

2. *The solution enters the stomach and begins to fill it.*

3. *Under an X-ray scan, the barium-filled stomach shows up clearly.*

Vacuum tube

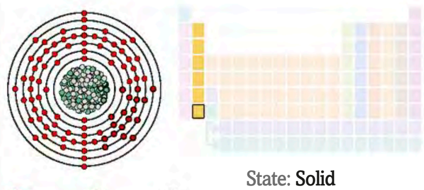
The barium in the metallic strip *absorbs gases in the tube, maintaining a vacuum.*

X-ray scan

The intestine *is filled with a barium solution.*

element is used in **spark plugs** to make them produce more powerful sparks and is added to **glass** to increase its shine. Barium compounds are added to some types of clay used for making **pots** and vases. In oil wells, barium compounds are added to drilling fluids to increase their density. Doctors make use of barium's density by giving patients a solution of barium compound to swallow, before taking **X-rays** of their digestive system. The barium makes the soft digestive organs denser, allowing them to be seen clearly with an X-ray machine.

88
Ra
Radium



88 88 138
State: Solid
Discovery: 1898

Forms

Chunk of uraninite

This ore contains just 0.7 g (0.02 oz) of radium in every 1,000 kg (2,205 lb) of rock.

In **100 years** time, only 4% of the radium atoms in this watch would have broken down.

Radium is the only radioactive member of the alkaline earth metals. It is also the rarest element in this group, and forms in small amounts when the atoms of more common metals – such as uranium and thorium – break down. Radium atoms do not survive for long, with most of them quickly decaying into radon, a radioactive noble gas. This element is highly dangerous and is rarely used today. However, in the early 20th century, radium compounds were in common use. Luminous paints, like those used to make **watch dials**

Uses

PIERRE AND MARIE CURIE

Radium was discovered in 1898 by Marie and Pierre Curie. They found that uranium ores produced more radioactivity than expected from samples of uranium. They realized another radioactive metal was present and named it radium.

The radium paint *in this clock makes the numbers glow green-blue in the dark.*

Pocket watch with a luminous dial

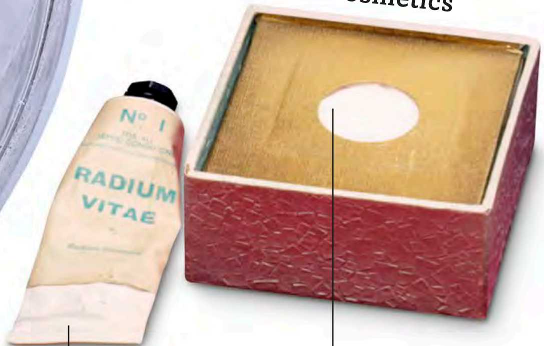
This vial *contains a liquid called radium chloride.*

Vials for radium treatment

This machine *from the early 20th century mixed radium into water, which was thought to make it healthier to drink.*

Radium emanator

Cosmetics

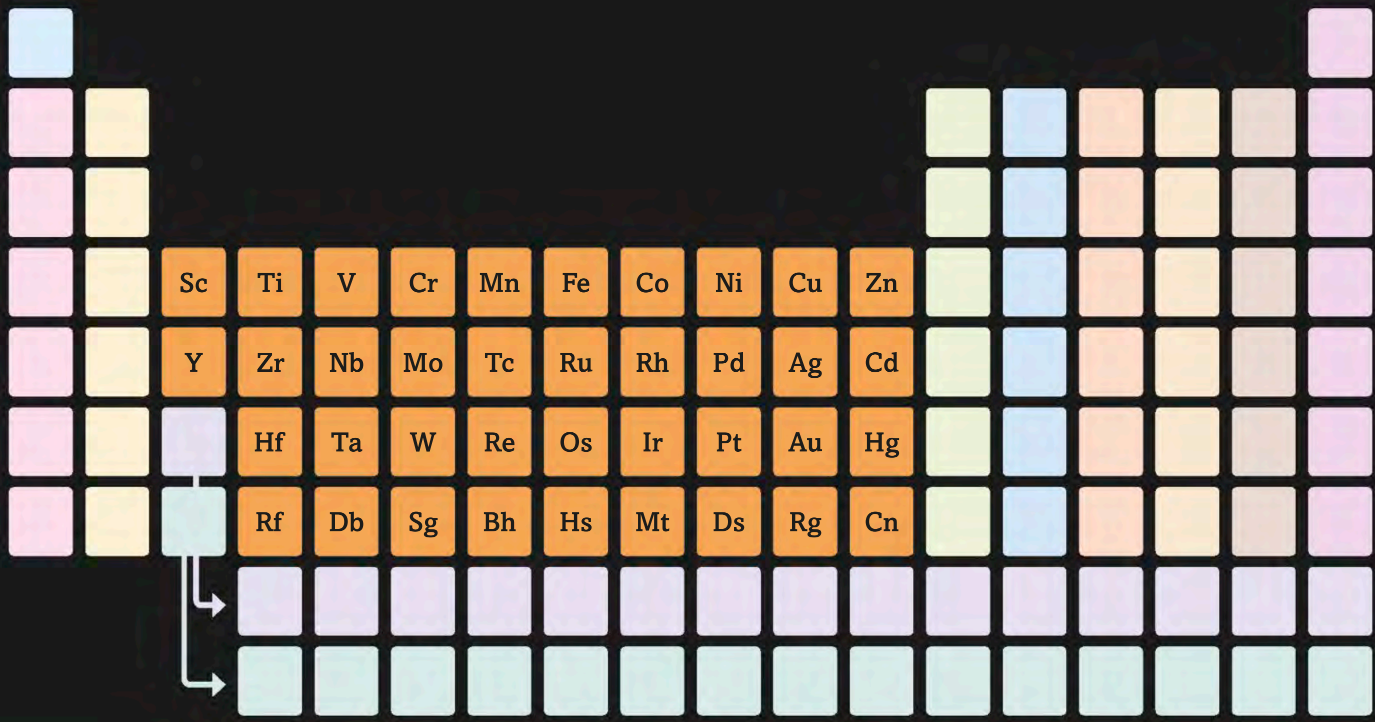


Skin lotions *containing radium were common in the 1920s.*

Radium face powder *was once thought to be good for the skin.*

glow in the dark, were created using radium. People working with this paint often became ill, especially with cancer, because the radiation produced by radium damages DNA. Nevertheless, until the 1940s, many people thought radium's radioactivity made them stronger, not weaker. They injected themselves with **vials containing a radium compound**, believing it gave them an energy boost. They also thought that creams and **cosmetics** with radium in them made the skin healthier, even though they did exactly the opposite.

Oddly shaped piece of pure cobalt (Co).



Transition Metals

This is the largest set of elements in the periodic table. This block of metals contains useful elements, such as gold (Au), iron (Fe), and copper (Cu). Many of these metals are easy to shape. The fourth period of the block – from rutherfordium (Rf) to copernicium (Cn) – are artificial and do not occur in nature. They were created by scientists in laboratories.

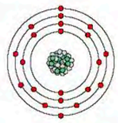
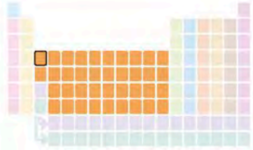
Atomic structure
Most transition metals have two outer electrons, but a few, such as copper (Cu), have just one.

Physical properties
These elements are generally hard and dense metals. Mercury (Hg), the only element that is liquid at room temperature, also belongs to this group.

Chemical properties
Transition metals are not as reactive as alkali and alkaline earth metals. However, they form many varied and colourful compounds.

Compounds
Many compounds of transition metals are brightly coloured. These metals are often used in alloys, such as brass and steel.

21 Sc Scandium

21 21 24

State: Solid
Discovery: 1879

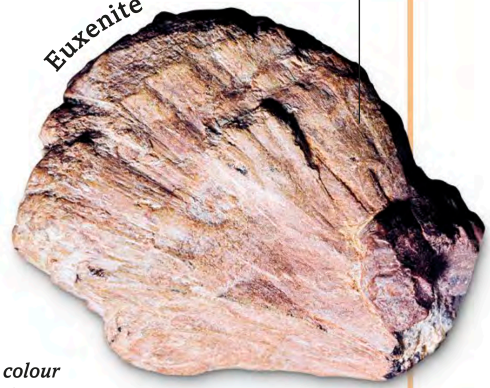
Forms

Greasy texture

Gadolinite

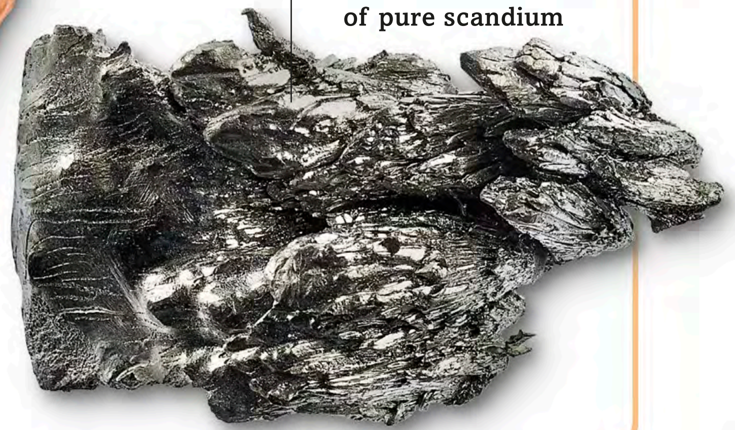
These crystals contain only tiny amounts of scandium.

Euxenite



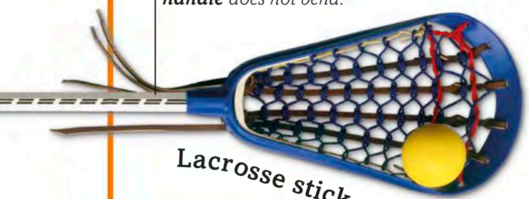
The silvery colour of this metal turns yellow in the air.

Laboratory sample of pure scandium



Uses

This lightweight alloy handle does not bend.



Lacrosse stick

The scandium iodide gas inside the tube glows with a bright bluish light.

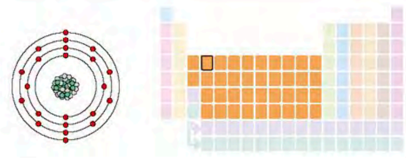
Metal halide lamp

MiG-29 aircraft

Some high-speed jets have a fuselage made of scandium alloys.

A soft and lightweight metal, scandium is similar to aluminium. It is spread so thinly in Earth's rocks that it is very difficult to collect a large amount of this element. Scandium is only used for specialist applications. Its main ores are the minerals **gadolinite** and **euxenite**, which also contain small amounts of many other rare metals, such as cerium and yttrium. Scandium mixed with aluminium makes a strong alloy, which is used in lightweight equipment for sports, such as **lacrosse**, and to make high-speed jets, such as the **MiG-29**.

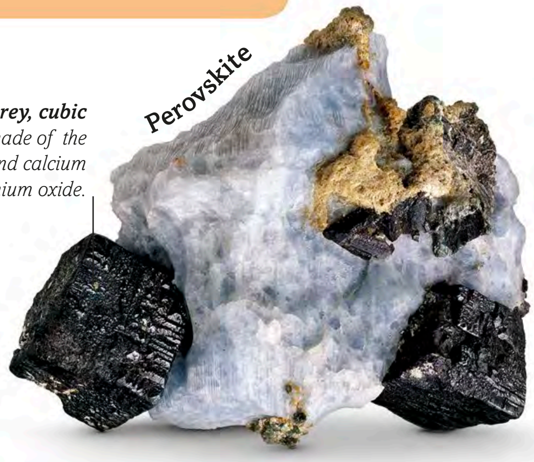
22
Ti
Titanium



22 22 26

State: Solid
Discovery: 1791

Forms



Perovskite

This grey, cubic crystal *is made of the compound calcium titanium oxide.*

Brookite

This large, deep red crystal of brookite *contains titanium dioxide.*

These are crystals *of the mineral albite.*

This metal's shine fades to grey *when exposed to air.*

Laboratory sample of pure titanium

Uses

The titanium plate *placed inside acts as as shield.*

Body armour

Artificial hip joint

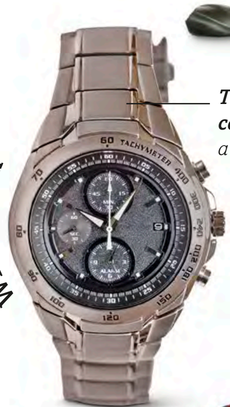
This titanium joint *can replace damaged bone in body.*

Sunscreen

The titanium dioxide *in this sunscreen blocks damaging ultraviolet (UV) radiation in sunlight.*

Drill bit

This drill bit *is hardened with a coating of titanium nitride.*



Wristwatch

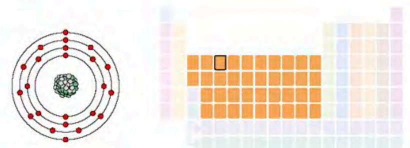
This watch casing *is made of a titanium alloy.*

Roller blades

This titanium frame *is lightweight but strong.*

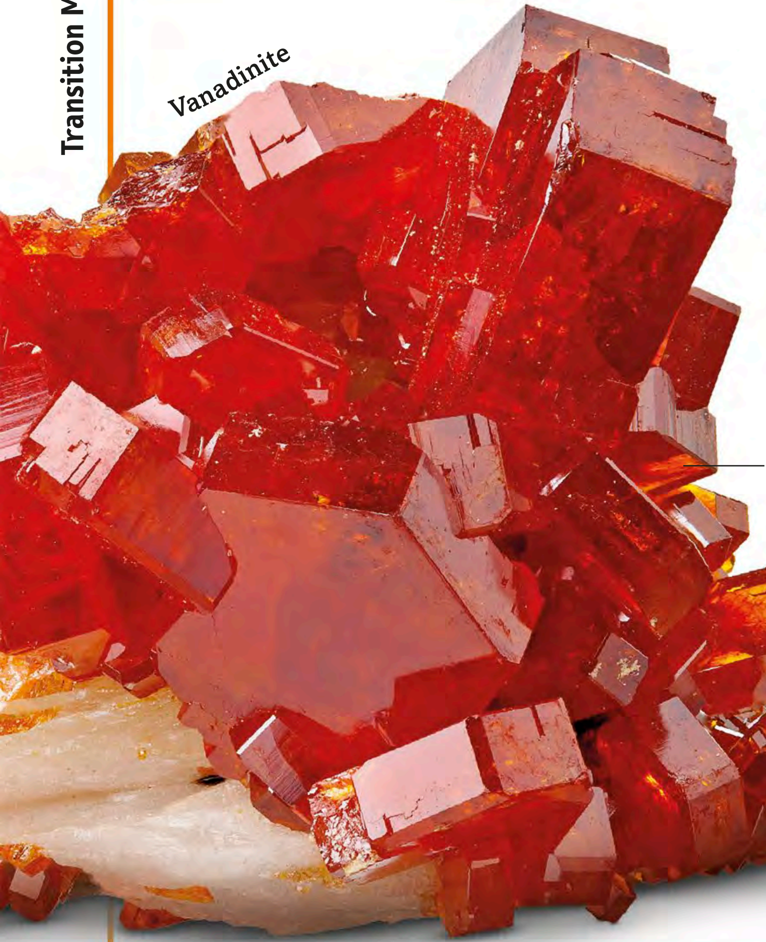
Named after the Titans, a race of mythic Greek gods, titanium is a silvery metal. It is as strong as steel but much lighter, and it is not corroded by water or chemicals. This strong metal also makes excellent protective shields in **body armour**. Titanium is commonly used to prepare titanium dioxide, a compound of titanium and oxygen that is used in paints and **sunscreen**. Titanium is not toxic so it can be used to make medical implants, such as artificial **hip joints**. **Wristwatches** made with titanium alloys are light and strong.

23
V
Vanadium



23 23 28
State: Solid
Discovery: 1801

Forms



Vanadinite

These brittle ***crystals*** *are the main source of vanadium.*

Fly agaric mushroom

This mushroom *contains high levels of vanadium.*

Carnotite

This powdery yellow crust *contains tiny amounts of vanadium.*

Laboratory sample of pure vanadium crystals

Silvery surface

Uses

Spanners

Tools *made with alloys of vanadium and steel are durable.*

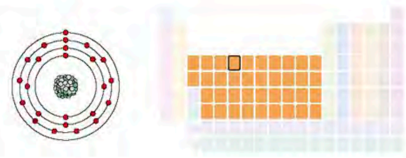
About **85% of all vanadium** is used to toughen steel.

Damascus Steel knife

This knife *has been strengthened by the addition of vanadium.*

Vanadium can be hammered and stretched without breaking. This hard, strong metal is easy to shape. **Vanadium** was first **purified** in 1869 by the British chemist Henry Roscoe. Today, it is commonly extracted from its ore **vanadinite**. Ancient metalworkers used tiny amounts of vanadium compounds to make a very tough substance called **Damascus Steel**. This was named after the capital city of Syria, where ironworkers made the world's sharpest swords. Vanadium is still used to toughen tools, such as **spanners** and knives.

24 Cr Chromium



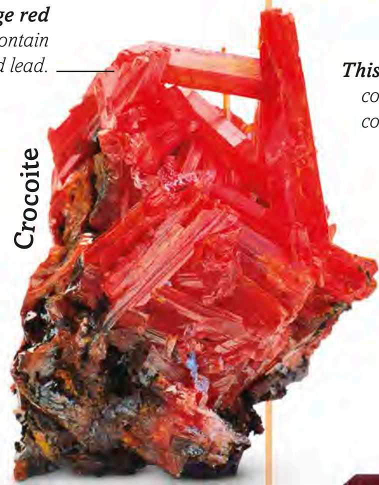
24 24 28

State: Solid
Discovery: 1798

Forms

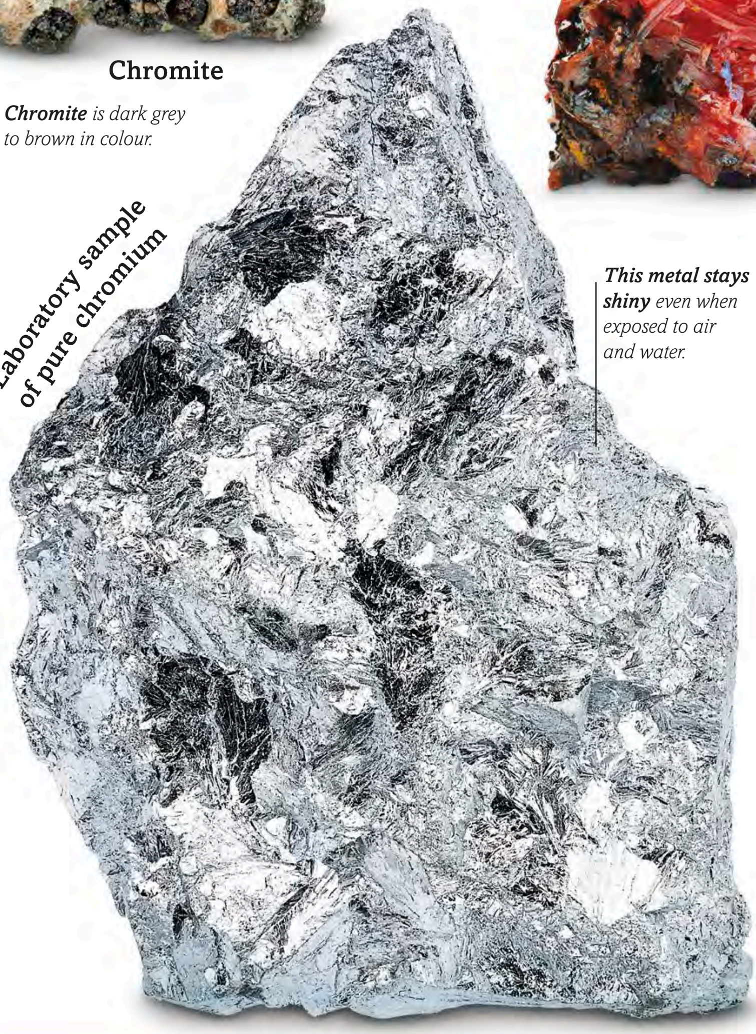
Chromite

Chromite is dark grey to brown in colour.



Crocoite

***These large red crystals** contain chromium and lead.*



Laboratory sample of pure chromium

***This metal stays shiny** even when exposed to air and water.*

Uses

Stainless steel kitchenware

***This grater** can resist corrosion because it contains chromium.*

Ruby

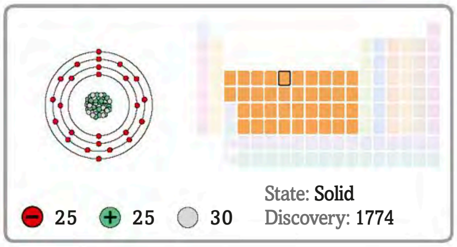
***This red colour** is due to the presence of tiny amounts of chromium oxide in the crystal.*

Motorcycle

***The chromium plating** protects this motorbike from rusting.*

Chromium is named after *chroma*, the Greek word for "colour". Many minerals of chromium, including **chromite** and **crocoite**, are brightly coloured. An artificial form of crocoite, known as "chrome yellow", was once used in paints, but it was banned when scientists discovered it to be poisonous. **Pure chromium** doesn't corrode easily, so it is combined with iron and carbon to produce **stainless steel**. Chromium also gives gemstones, such as **rubies**, their deep-red colour. Some **motorcycles** have chromium-plated bodywork, giving them a shiny finish.

25
Mn
Manganese



Forms

Manganese was **purified** from **pyrolusite** for the first time in 1774.

Like magnesium, this element gets its name from the Greek region of Magnesia. There are many manganese minerals, including the colourful mineral **rhodochrosite**. The pure form of the metal is obtained mainly from the ore **pyrolusite**. **Pure manganese** is dense, hard, and brittle. This element is present in seawater as the compounds manganese hydroxide and manganese oxide, which have built up in layers over millions of years to form masses on the sea bed. The human body needs a tiny amount of manganese, which we can get

Manganese-rich food

Laboratory sample of pure manganese

Uses

Jefferson nickel

***This US coin** from World War II was made using manganese and silver because nickel was in short supply.*

***These steel tracks** have manganese added to them to make them stronger.*

Railway tracks

Dry cell battery

***This battery** contains manganese dioxide.*

Unleaded petrol

***This petrol** contains a manganese compound, which is less toxic than lead.*

***The black colour** comes from manganese dioxide.*

Lascaux cave paintings, France

Purple glass bottle

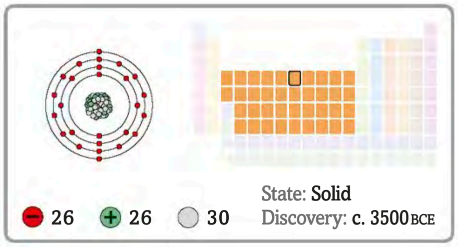
***This glass is coloured** by adding a manganese compound called permanganate.*

JOHAN GOTTLIEB GAHN

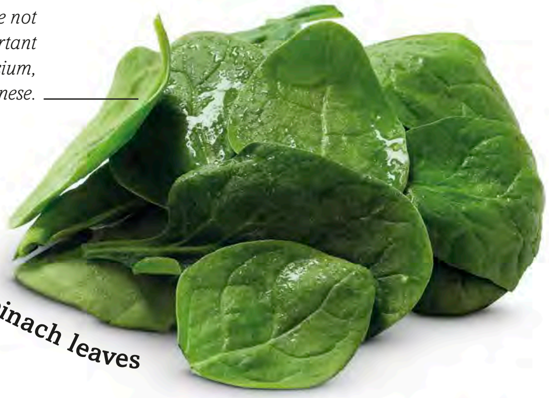
In 1774, Swedish chemist Johan Gottlieb Gahn discovered manganese by reacting manganese dioxide with charcoal – which contains carbon – under a lot of heat. The carbon took the oxygen away from the compound, leaving behind pure manganese.

from mussels, nuts, oats, and pineapples. The applications of manganese include its use in strengthening steel, which is used in making **railway tracks** and tank armour. Certain **dry cell batteries** carry a mixture containing manganese oxide. Manganese compounds are also added to **petrol** and used to clean impurities from **glass** to make it clear or to give it a purple colour. In prehistoric times, the compound manganese dioxide was crushed to make the dark colours used in **cave paintings**.

26
Fe
Iron



Forms

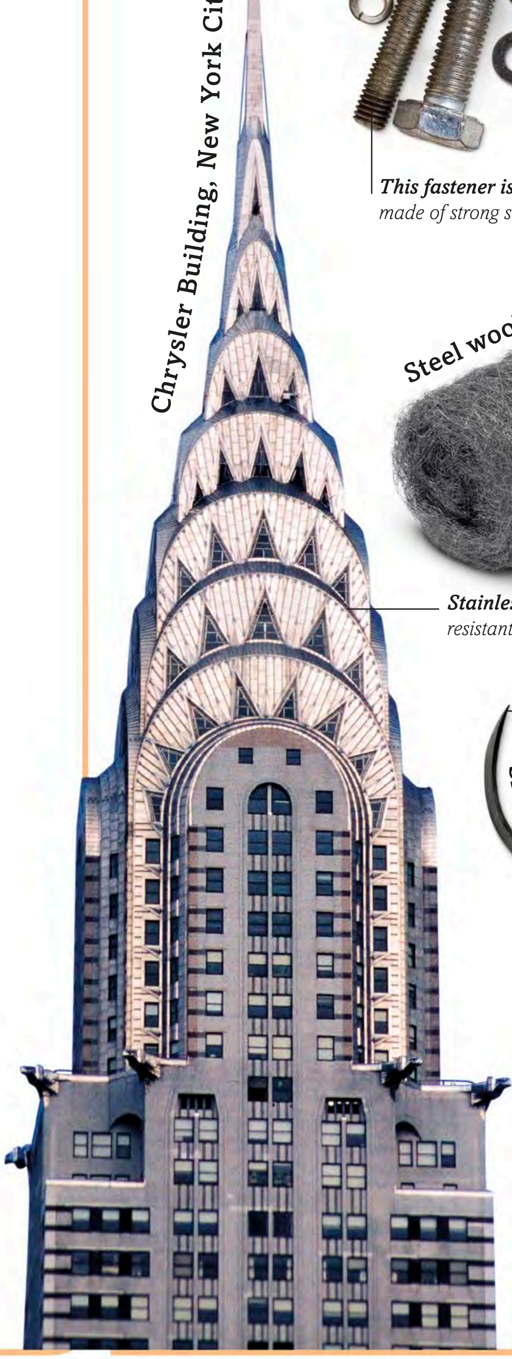


Iron is the **most common metal** on our planet.

Most of the iron on our planet is locked away in Earth's hot, molten core. This element is widely found in rocks worldwide, and almost 2.5 billion tonnes of iron is purified every year. Mineral ores rich in iron include **pyrite**. Other ores, including haematite, are used to extract **pure iron** in a process called smelting. **Iron-rich meteorites** – chunks of rock from outer space that crash to Earth – are one of very few sources of naturally pure iron. The human body uses iron to make haemoglobin, a substance in blood that carries oxygen around our body (oxygen helps

Uses

Chrysler Building, New York City, USA



Stainless steel is quite resistant to rain and wind.

Nuts and bolts

This fastener is made of strong steel.

Tractor

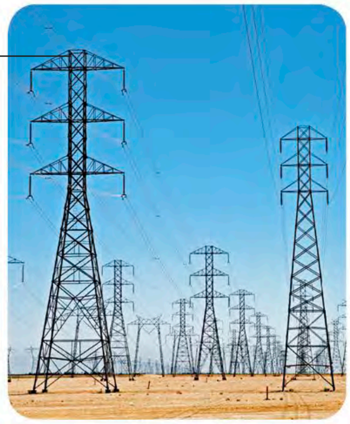
This steel body resists rusting.

Steel wool

Thin wires of steel are used to clean hard surfaces.

Cast iron pot

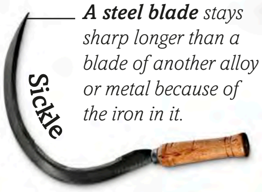
This iron pot retains heat well while cooking.



These tall structures are made from stiff steel girders.

Transmission towers

Sickle

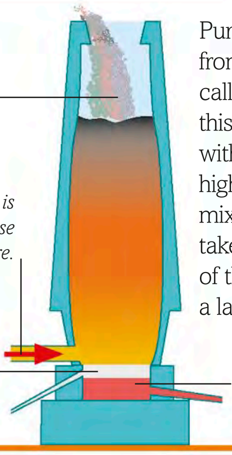


A steel blade stays sharp longer than a blade of another alloy or metal because of the iron in it.

Iron filings and magnet

These small grains of pure iron are magnetic and are attracted to the end of a magnet.

SMELTING



1. Iron ore and coal are added to the furnace.

2. Hot air is added here to raise the temperature.

3. Impurities float on the pure metal, then released.

4. Pure iron sinks to the bottom, then removed.

Pure iron is separated from its ores in a process called smelting. During this process, iron reacts with carbon in coal at a high temperature. As the mixture burns, the carbon takes the impurities out of the ore, leaving behind a layer of pure iron.

our cells produce energy for the body to work). Foods containing iron include meats and green vegetables, such as **spinach**. When pure iron comes into contact with air and water, it develops a flaky, reddish-brown coating called rust, which weakens the metal. In order to make iron tougher, tiny amounts of carbon and other metals, such as nickel and titanium, are added to it. This forms an alloy called steel, which is used to make **bolts** and strong **tractor** bodies, among other applications. Adding the element chromium to steel creates a stronger alloy called stainless steel.

STEELMAKING A stream of red-hot, liquid metal pours from a furnace at a steelmaking workshop. This is the end of a long process in which iron ore is transformed into steel, a tough alloy that is strong enough to make girders for supporting skyscrapers and bridges. The steel may even be moulded into car bodies, woven into superstrong cables for elevators, or turned into powerful magnets that can levitate maglev trains.

Steel is an alloy of iron that contains about two per cent carbon and some other elements. The carbon locks all the atoms together and prevents the metal from cracking. This makes steel harder than iron: it bends before it breaks and doesn't shatter easily. To make steel, iron ore is smelted in a blast furnace to remove its impurities, such as nitrogen, sulfur, or phosphorus. Other elements can be added to create different varieties of steel. For example, chromium in steel stops it from rusting, while manganese makes it harder. Adding silicon to steel can make the alloy more magnetic, while nickel makes it less brittle at extremely low temperatures.

27
Co
Cobalt

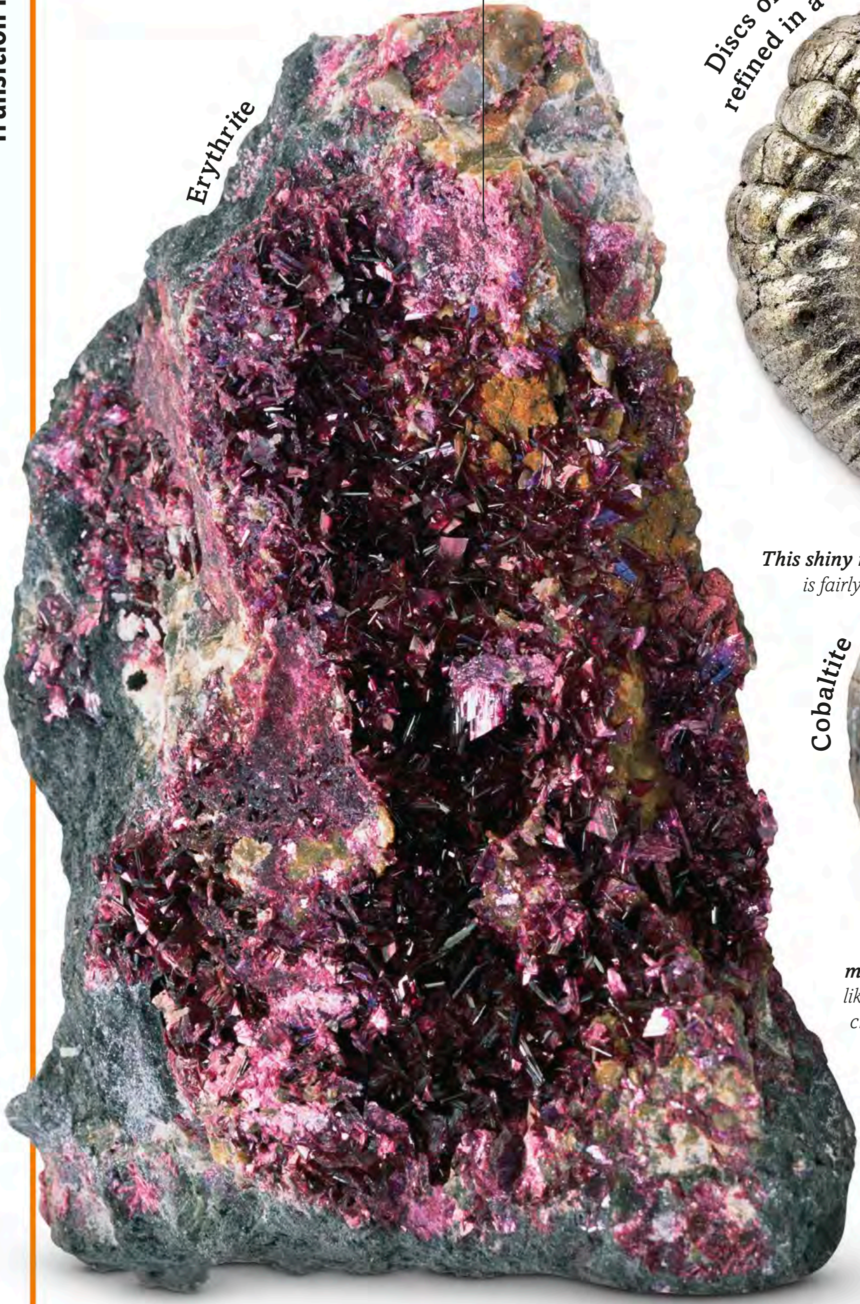
27 27 32

State: Solid
Discovery: 1739

Forms

Erythrite

The distinctive purplish colour *gives it the nickname "red cobalt".*



Discs of pure cobalt refined in a laboratory

This shiny metal *is fairly hard.*

Cobaltite

These cubic crystals *contain a sulfur compound of cobalt.*

This silvery mineral *smells like garlic when crushed due to the presence of arsenic.*

Skutterudite

Medieval German miners often mistook ores of cobalt for precious metals. When they tried to purify these, the arsenic gas released made them sick. This unwanted side-effect led to the name *kobold*, which is German for "goblin", a mischievous spirit.

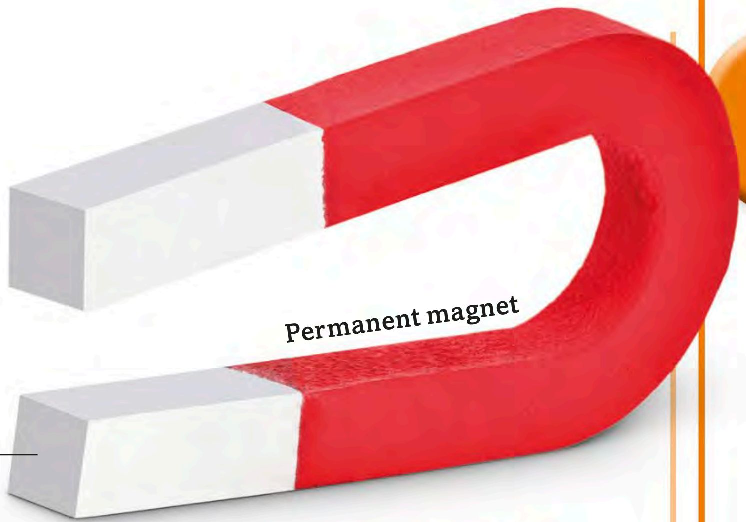
Pure cobalt is hard and shiny, and is added to steel and other alloys to make them stronger. Alloys containing cobalt are used in the blades of **jet engines** and in **artificial joints**, such as hip and knee joints. Cobalt is one of the few elements

Uses

Artificial hip joint

This part of ***the joint*** *is screwed into the hip bone.*

Tough and lightweight artificial joints *can be made from an alloy of cobalt and chromium.*



Permanent magnet

This magnet *can work at temperatures as high as 800°C (1,400°F).*

These blades *made of a cobalt alloy stay hard even when very hot.*

Jet engine turbine

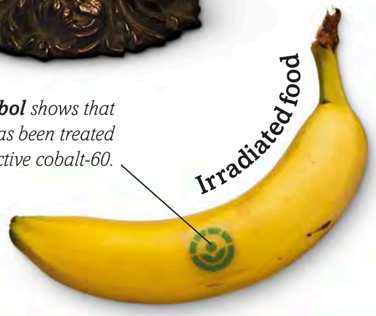
Tiffany lamp

This blue glass *is manufactured using cobalt compounds.*

Cobalt blue paints have been in use **since 3000 BCE**.

Cobalt blue paint

This intense colour *does not fade easily over time or upon exposure to light.*



Irradiated food

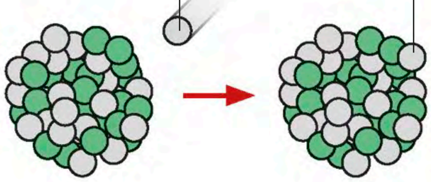
This symbol *shows that this fruit has been treated with radioactive cobalt-60.*

FORMING AN ISOTOPE

Cobalt-60 is an isotope, or form, of this element. It is created artificially in nuclear reactors. Because of its radioactivity, it is useful in some cancer treatments.

A neutron is fired at the cobalt-59 nucleus.

Added neutron

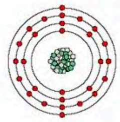
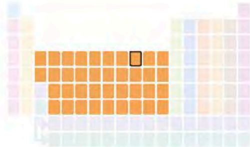


Cobalt-59 is a stable atom with 59 neutrons.

Cobalt-60 is a radioactive atom with 60 neutrons.

that can be used to make a permanent magnet. Large **permanent magnets** are made from a tough alloy of cobalt, nickel, and aluminium, called alnico. A radioactive form of cobalt, called cobalt-60, is produced in nuclear reactors. This form is widely employed to **irradiate food**, a process by which food is exposed to a tiny dose of radiation to kill harmful germs. Cobalt can also produce a deep shade of blue: **cobalt blue paints** and dyes are formed by reacting aluminium with cobalt oxide.

28
Ni
Nickel

28 28 30

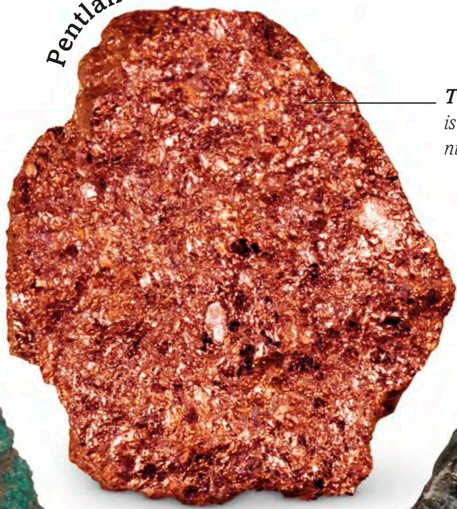
State: Solid
Discovery: 1751

Forms

Garnierite

***This green colour** comes from the presence of nickel.*

Pentlandite



***This reddish mineral** is made of iron and nickel sulfide.*

Nickeline

***This nickel ore** also contains arsenic.*

Pure nickel balls refined in a laboratory

***These silvery white metal pellets** have a yellowish tinge.*

Nickel is named after Old Nick, a demonic spirit from Christian lore that was believed to live underground. In the 18th century, German miners mistook a poisonous nickel mineral, now known as **nickeline**, for a copper ore. When this mineral failed to yield copper, they named it *Kupfernickel*, meaning "Old Nick's copper". Nickel is also found in other ores, such as **garnierite** and **pentlandite**. This element is one of the most useful metals, with a number of applications. Because **pure nickel** does not rust, it is used to coat objects to make

Uses

Nickel goblet drum

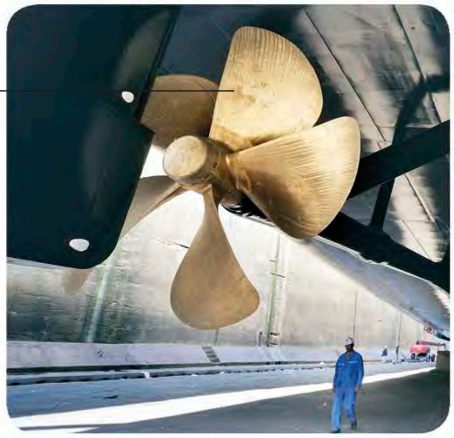
This nickel-plated instrument has a shiny finish.

Nickel-plated dagger

Rust-resistant handle

Nickel-based coin

The US five cent coin *is made of an alloy of 75% copper and 25% nickel.*



Ship propeller

Nickel-copper alloy plating *makes propellers strong and durable.*

Electric guitar

These nickel-plated guitar strings *help create a clear tone.*

This **coin** from the **USA**, made of a nickel-copper alloy, is called a **nickel**.

Nickel cutlery

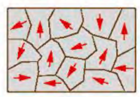
This silver-coated fork *is made of an alloy of nickel, copper, and zinc.*

Toaster

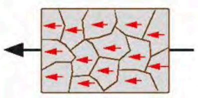
Nickel alloy wires *heat up to make toast.*

PERMANENT MAGNETS

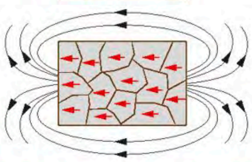
A temporary magnet works when it is put in a magnetic field, but a permanent magnet retains its charge even when it is taken out of that field. Nickel is one of only a few elements that can be used to make permanent magnets.



__1__. Atoms in a piece of nickel metal are arranged randomly.



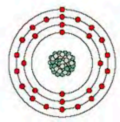
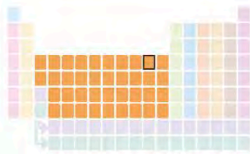
__2__. When a magnetic field is applied, the atoms align in one direction.



__3__. The atoms then stay aligned and produce a magnetic field of their own, even after the external field is removed.

them look like silver – a trick still used to make inexpensive ornamental objects. Nickel is also mixed with copper to make an alloy called cupronickel. This is used as plating on **propellers** and other metallic parts of ships, as the alloy does not corrode in seawater. The same alloy is used in most of the world's silver-coloured **coins**. Nickel is used in the strings of **electric guitars**. This element is added to chromium to make an alloy called nichrome. Wires made of this alloy conduct heat very well, so are used in **toasters**.

29
Cu
Copper

$-$ 29 $+$ 29 35 State: **Solid** Discovery: **Prehistoric**

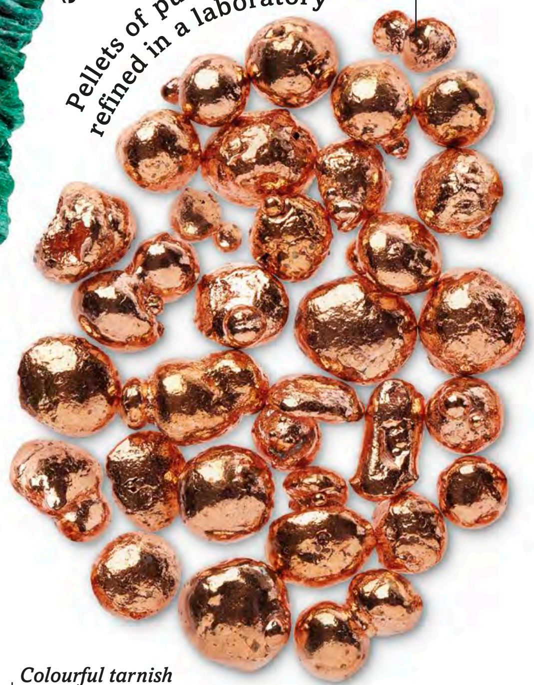
Forms

Copper growth on limonite

Branchlike crystals *of copper*

Malachite

In caves, feather-like crystals *are often formed.*



Pellets of pure copper refined in a laboratory

Unique reddish orange colour

Chalcopyrite

These golden yellow crystals *contain copper sulfide.*

Bornite

Colourful tarnish *develops when the mineral reacts with air.*

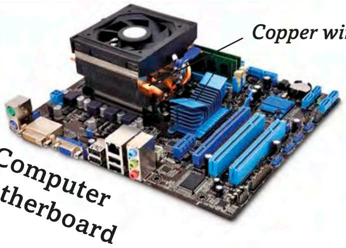
Crustacean blood

Crustacean blood is blue *because it contains copper.*

Copper is a soft, bendy metal that is an excellent conductor of electricity and heat. Although it is one of the few elements found pure in nature, most of it exists in ores such as **chalcopyrite**. Other copper minerals, such as **malachite** and azurite, are brightly coloured.

Copper is the only metal that has a reddish colour in its pure form. **Pure copper** is mainly used as **wires** in electrical equipment. Copper wire wrapped around an iron core and then electrified helps create an **electromagnet**. Because they can be switched on or off, electromagnets can

Uses



Copper wire

Computer motherboard

Giant electromagnet

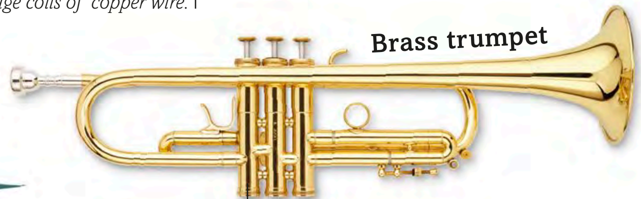
Massive crane-mounted electromagnets contain huge coils of copper wire.

Electroplated nails

Copper coating on steel *slows down corrosion.*

Statue of Liberty, New York City, USA

A verdigris layer *protects pure copper from additional weathering.*



Brass trumpet

The brass tube *contains air that vibrates to produce musical sounds.*

Bronze helmet

This tough alloy *does not weaken over time.*

Copper-glazed vase

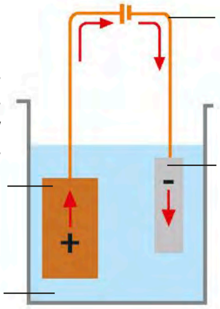
A copper glaze *on the vase gives it a metallic shine.*

Copper electrical wires

Pure copper *can be stretched to form long wires.*

ELECTROPLATING

A thin layer of copper can be added to metal, usually iron, to stop it from corroding easily. This process is called electroplating.



Electrons flow from the positive to the negative electrode.

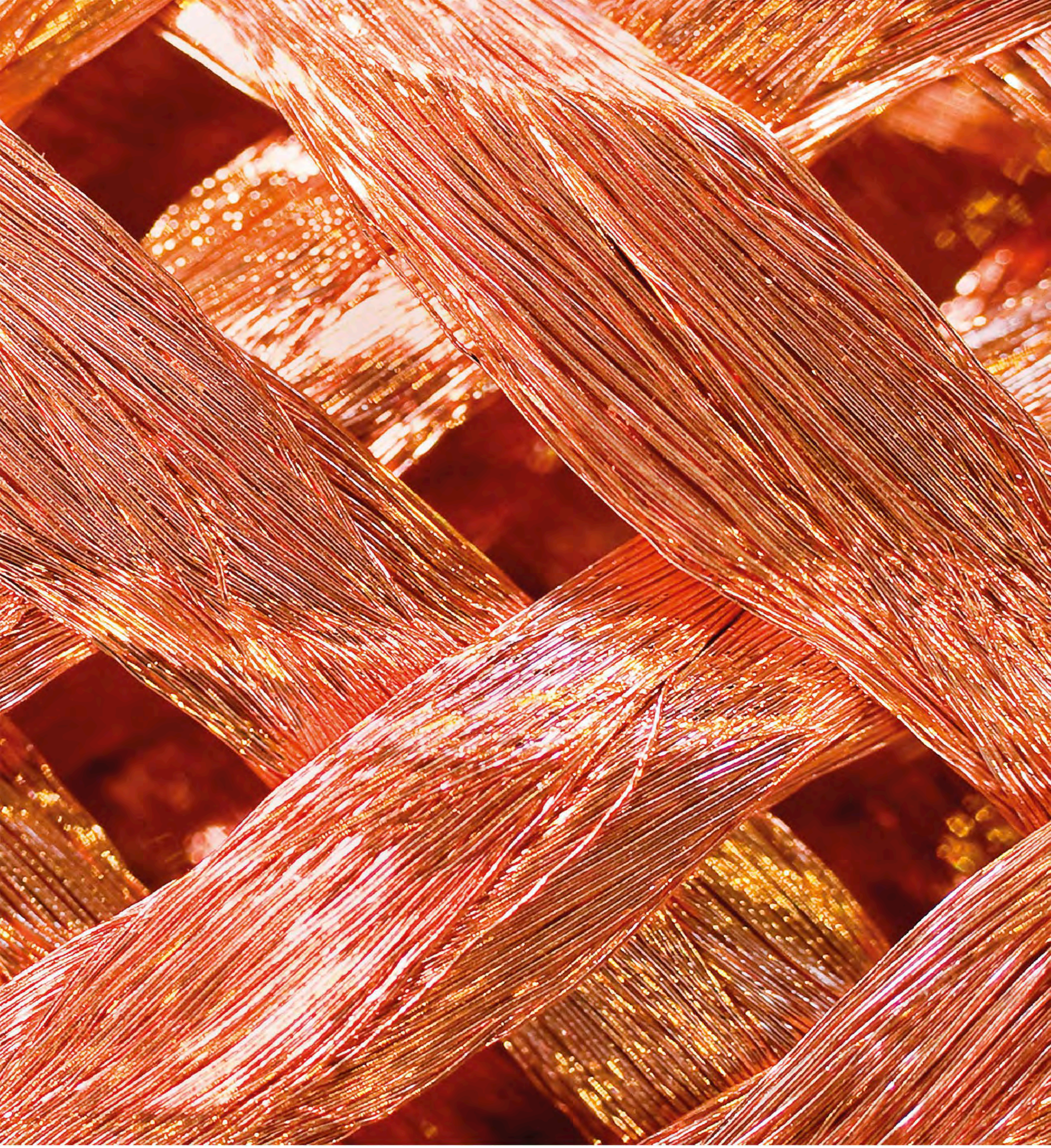
This positive electrode is made of copper and slowly dissolves in the liquid.

This solution contains dissolved copper ions.

This electrode is made of iron. Copper ions form a protective coating over the metal.

be magnetic as and when they are needed. They can be much more powerful than normal magnets and can lift heavy objects. Pure copper does not rust, but it reacts with air over time to form a layer of grey-green copper carbonate called verdigris. This can be seen on copper statues, such as the **Statue of Liberty**. Copper is often mixed with other metals to produce tougher alloys. Bronze, a copper-tin alloy, is more durable than pure copper and has been used since ancient times. Brass, a copper-zinc alloy, is used in musical instruments, such as **trumpets**.

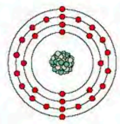
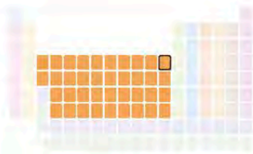
COPPER WIRES Not much thicker than a human hair, these copper wires are twisted together and woven into a tight bundle. One of the main uses for these wires is to shield a thicker copper wire that transmits a signal to a television. As the signal carries pictures and sounds in the form of electrical currents, the wires wrapped around it prevent interference from other electrical sources nearby.



Copper is a very good conductor of electricity, but not the best; silver is better. However, copper is more widely used because it is much cheaper to find and purify. Each year, about 15 million tonnes of pure copper is produced, and more than half of it is used to make electrical components, such as this mesh. Today, more than a billion kilometres of copper wiring is running unseen in power supplies, buildings, and electronics. Copper is now the most common electrical metal, but it has a long history. It was the first element to be refined from ores in large amounts about 7,000 years ago in the region that is now Iraq. Today, Bingham Canyon in Utah, USA, is the world's largest copper mine.

30

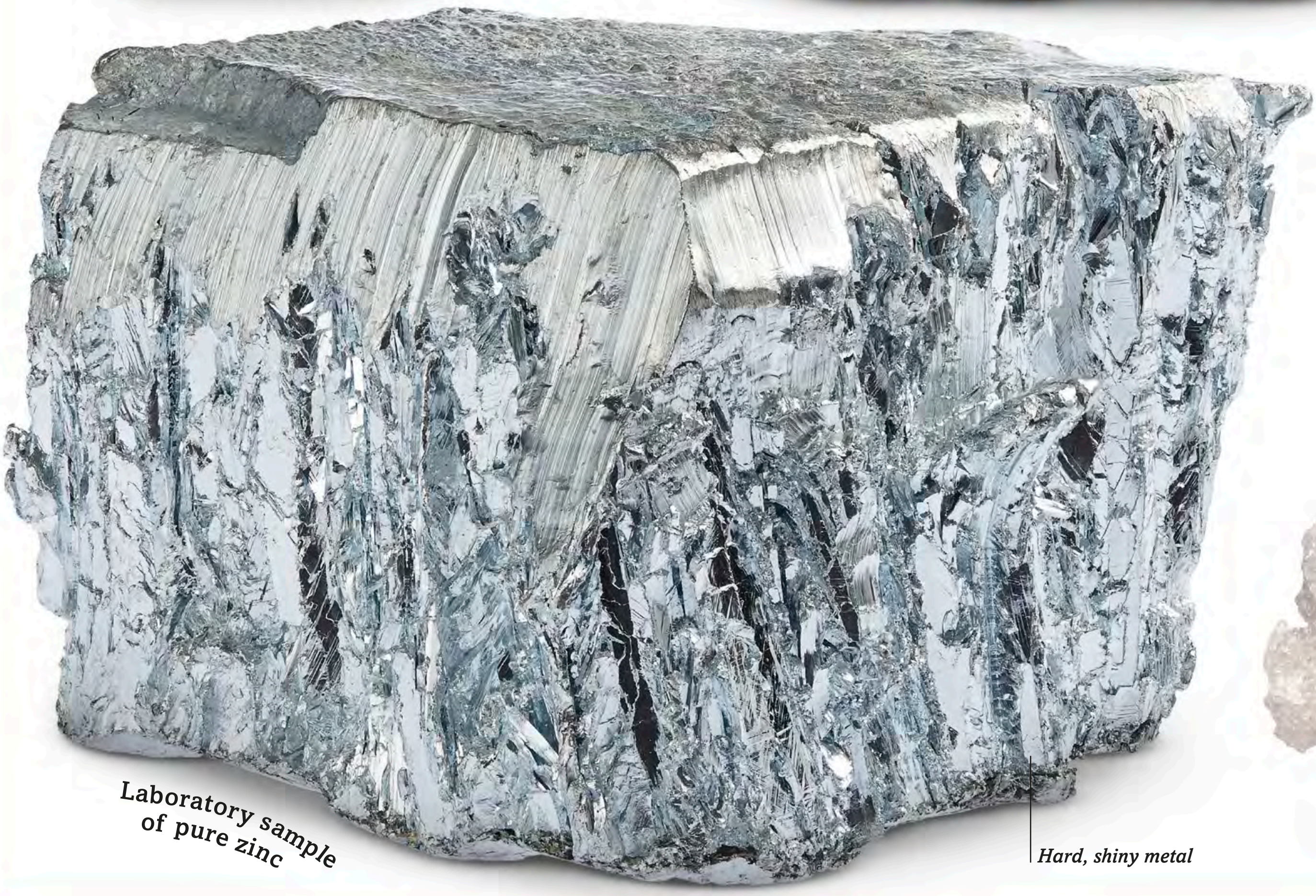
Zn Zinc

30 30 35

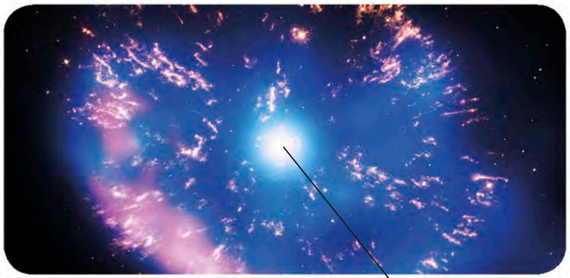
State: Solid
Discovery: 1746

Forms



Zinc was used in India and China hundreds of years before the German chemist Andreas Marggraf identified it as a new element in the 18th century. This element is a rare transition metal that is never pure in nature, but is found in many minerals.

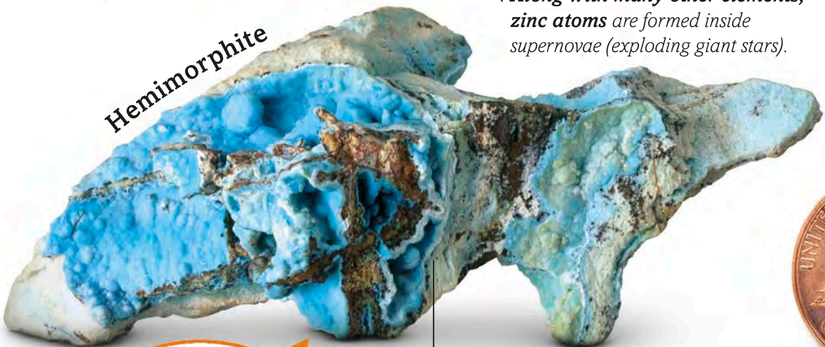
The mineral **sphalerite**, containing zinc sulfide, is the major source of **pure zinc**. Another principal mineral, **hemimorphite**, contains zinc and silicon. Zinc is essential in our diet. We consume it from food such as cheese and sunflower seeds. Zinc compounds have a wide



Supernova

*Along with many other elements, **zinc atoms** are formed inside supernovae (exploding giant stars).*

Hemimorphite



__This mineral__ contains zinc carbonate.

Hemimorphite was discovered by James Smithson, the founder of the **Smithsonian** Institution.

__Zinc oxide crystals__ are generally colourless.

Zincite

Uses

First-aid tape

__Medical tapes__ that contain zinc oxide stop wounds from getting infected with microbes.

__The zinc coating__ on this steel bridge protects it from rust.

Akashi Kaikyo Bridge, Kobe, Japan

American penny

__This zinc coin__ is coated with copper.

Rubber boots

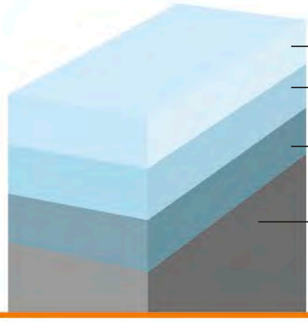
__This flexible rubber__ is made stronger by adding zinc oxide.

__This soothing skin lotion__ contains a mixture of zinc compounds.

Calamine lotion

GALVANIZED STEEL

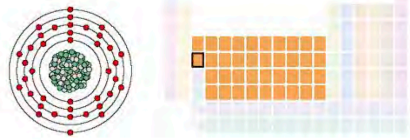
Steel is protected from corrosion by coating it with zinc. Alloys of iron and zinc form in layers between the steel and pure zinc. This process is called galvanization.



range of applications. For example, a compound of zinc and oxygen called zinc oxide is used in **medical tape** and sunscreen. Zinc oxide can also be used to toughen the rubber used in **boots** and tyres. A compound of zinc and sulfur called zinc sulfide is used to make some paints that glow in the dark. When pure zinc is exposed to air, the metal reacts with oxygen to form a protective layer of an oxide. This coating can prevent objects covered in zinc, such as **bridges**, from corroding easily.

39
Y

Yttrium



39 39 50

State: Solid
Discovery: 1794

Forms

Yttrium is **400 times more common** in Earth's crust than silver.

Xenotime

This mineral *contains trace amounts of uranium, which is radioactive.*

Moon rock

This rock sample *was brought to Earth by NASA's Apollo 16 mission.*

Laboratory sample of pure yttrium

This silvery element *does not corrode easily.*

Cabbage

This vegetable *contains yttrium.*

Monazite

This reddish-brown mineral *contains about 2% yttrium.*

The samples of rock brought back from the Moon by astronauts in NASA's Apollo missions contained higher levels of yttrium than rocks on Earth. This element is never found in pure form in nature, but small traces of it are present in many minerals, including **xenotime** and **monazite**. Yttrium was discovered in a compound in 1794 by the Finnish chemist Johan Gadolin, but it wasn't isolated until 1828. Other yttrium compounds have since been found in vegetables, including **cabbage**, and in seeds of woody plants. In

Uses


LED lamp

This bulb contains yttrium compounds that enable it to produce a warmer, more yellow glow.


Laser

This laser is powered using crystals composed of yttrium and silicon, and can cut through metal.


Yttrium-90

This radioactive form of yttrium is used to treat cancers in the body.


Yttrium gas mantle

This fabric mantle holds the hot flame inside.

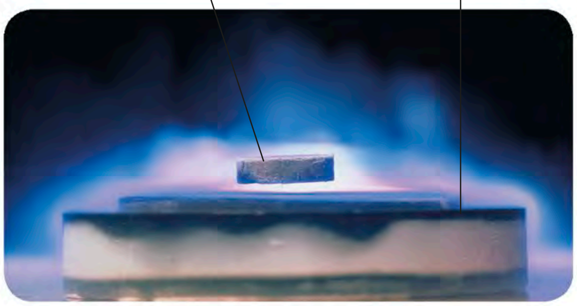

Digital camera lens

Shock-proof lenses are made from yttrium-infused glass to make them tough.

NASA spacecraft use yttrium lasers to map the **surface of asteroids** in space.

A small magnet floats over the superconductor.

This superconductor produces a magnetic field that repels the magnet above it.

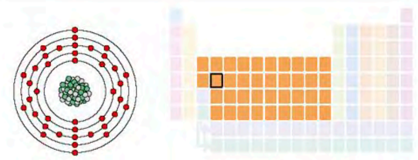

Yttrium superconductor

FRIEDRICH WÖHLER

In 1828, the German chemist Friedrich Wöhler became the first person to purify yttrium. He did so by extracting it from the compound yttrium chloride. He was also the first person to extract the metals beryllium and titanium from their ores.

LED lamps, yttrium converts blue light to other colours. Many **lasers** use an artificial mixture of yttrium and aluminium inside a silicon-rich crystal called garnet. Powerful yttrium lasers are used for treating some skin infections, as well as by dentists during tooth surgery. A radioactive form of this element has medical applications. Yttrium is added to the glass in a **camera lens** to make it tough. Yttrium compounds are also used in **superconductors** – materials that conduct electricity easily when cooled to very low temperatures.

40
Zr
Zirconium



40 40 51

State: Solid
Discovery: 1789

Forms

Bar of pure zirconium refined in a laboratory

This dark brown colour is caused by iron impurities.

This greyish-white pure element is easy to shape.

Zircon crystals

Uses

Dental crowns

These tough dental crowns are made of a zirconium-rich ceramic.

Ceramic knife

This hard, non-metallic blade does not require frequent sharpening.

This zirconium-filled bulb produces a bright light.

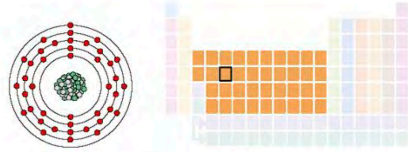
Camera flash from the 1960s

Zirconia crystal ring

This ring contains cubic zirconia crystals.

This element is named after the mineral zircon, which means "golden" in Persian, a reference to the golden-brown colour of its crystals. The Swedish chemist Jacob Berzelius was the first person to isolate **pure zirconium**, in 1824. Today, however, the element is mostly used in the form of the compound zirconium dioxide, or zirconia. Powdered zirconia is heated to produce a hard glass-like ceramic, which is used to create **dental crowns** and sharp **ceramic knives**. Powdered zirconia also forms sparkling **zirconia crystals** that look like diamonds.

41
Nb
Niobium



41 41 52

State: **Solid**
Discovery: **1801**

Forms

Columbite

This dark, dense ore *has a light metallic shine.*

Rods of pure niobium refined in a laboratory

This greyish pure metal *is soft.*

Columbite is named after the country of **Columbia**.

Uses

Pacemaker

The niobium case *houses a battery that regulates the beating of a human heart.*

Command Module from the Apollo 15 mission

This nozzle *made of a niobium alloy kept its shape even when very hot.*

Spectacle lenses

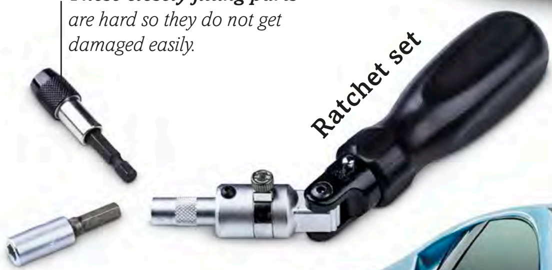
This pair of spectacles *has thin, powerful lenses made of a niobium compound.*

Niobium is so similar to the metal tantalum that the two were wrongly thought to be the same element for almost 40 years. The mineral **columbite** is the main source of this shiny metal. Niobium is not found naturally in its **pure form**. When extracted, it has many uses. As the element does not react adversely in the human body, it is used in implants, such as **pacemakers**. Niobium also does not expand when hot, so it is used to make parts of rockets, such as the one on the **Command Module** from NASA's Apollo 15 spacecraft that went to the Moon in 1971.

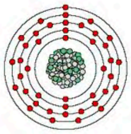
42
Mo
Molybdenum

Forms

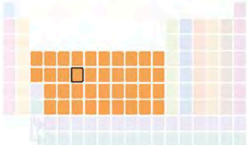
Uses



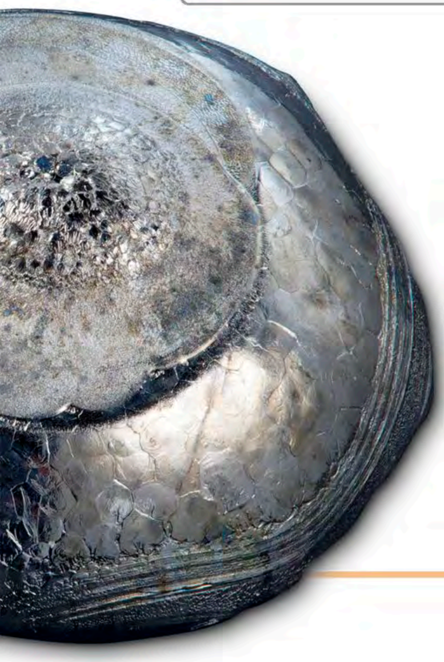
Molybdenum gets its unusual name from the Greek word *molybdos*, which means "lead". Miners once mistook **molybdenite**, a dark mineral containing this metal, for an ore of lead. This element is much harder than lead, so it is easy to distinguish between these two elements when they are pure. Molybdenite is soft and slippery, and it is the main molybdenum ore. **Pure molybdenum** is mainly used to make alloys that are resistant to corrosion. These are lightweight so are ideal for constructing **bike frames**, but



42 42 54



State: Solid
Discovery: 1781

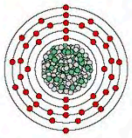


This experimental sports car is built with a rust-resistant alloy that contains molybdenum.

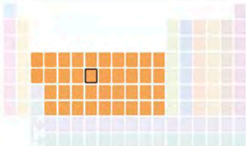
Vencer Sarthe

are hard enough for making sturdy tools, too. Molybdenum alloys are used in the latest designs of supercars, such as the **Vencer Sarthe**.

43 Tc Technetium



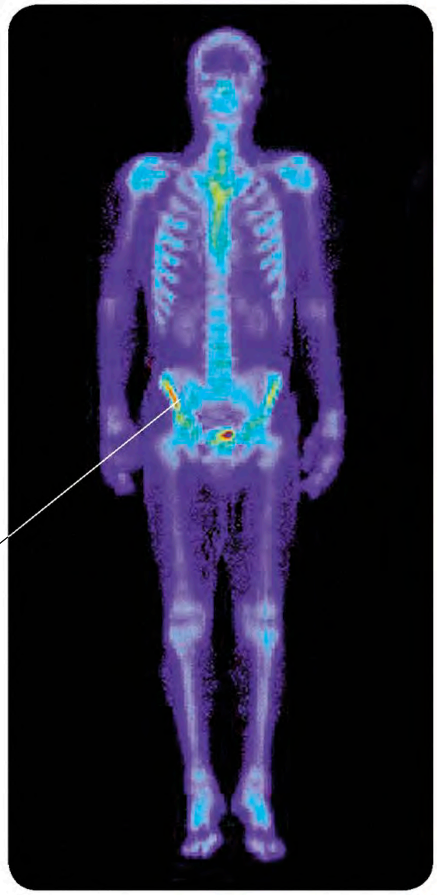
43 43 55



State: Solid
Discovery: 1937

This pure form of the metal *is produced inside nuclear reactors.*

Foil of pure technetium produced in a reactor



This body scan *was created using the radioactive effects of technetium.*

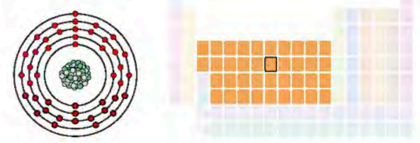
Technetium-based imaging

This box *contains radioactive molybdenum, which breaks down into technetium.*

Generating technetium

Technetium was the first element to be produced artificially by researchers. It is named after the Greek word for artificial, *tekhnetos*. Technetium does not exist in nature: any of its atoms that once existed on Earth broke down millions of years ago. Tiny amounts of this element were discovered in the waste produced by early nuclear reactors. Technetium is the lightest radioactive element. It is used extensively in **medical imaging**. It is injected into a patient's body, where it emits radiation for a short while. Some machines use this radiation to show bones clearly.

44
Ru
Ruthenium



44 44 57
State: Solid
Discovery: 1844

Forms

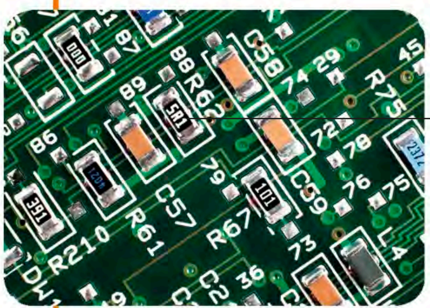
Pure ruthenium refined in a laboratory

These crystals have a bright, silver colour.

Pentlandite

This yellow-brown mineral is often found deep underground.

Uses



Electronic circuit board

This component contains ruthenium dioxide.

Toggle switch

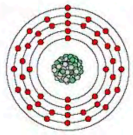
The metal alloy in the switch is toughened by adding ruthenium.

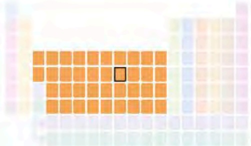
These low-cost solar panels are made using ruthenium.

SwissTech Convention Centre, Switzerland

Ruthenium is named after *Ruthenia*, an old Latin name for Russia. This rare metal is found in the mineral **pentlandite**, and its **pure form** is commonly extracted from this ore. A compound called ruthenium dioxide is used in several components in **electronic circuits**, including resistors and microchips for computers and other digital devices. Adding a small amount of ruthenium makes softer metals, such as platinum and palladium, much tougher. Moving parts in devices such as **switches** benefit from this property.

45
Rh Rhodium





45 45 58

State: Solid
Discovery: 1803

Forms

Pure rhodium pellet refined in a laboratory

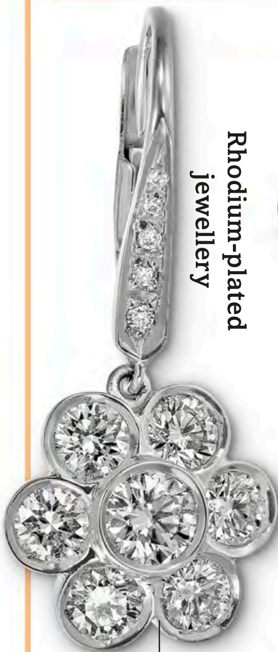
This metal *is shiny and silvery when pure.*

Millerite

This golden mineral *is defined by its needle-shaped crystals.*

Uses

Rhodium-plated jewellery



The rhodium plating *prevents jewellery from losing its shine.*

Headlight reflector

This rhodium-alloy reflector *provides a bright light.*

Rhodium-plated microscope

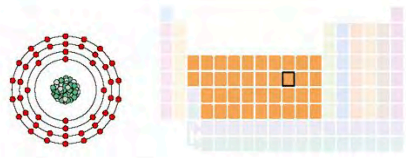
Parts of this microscope *are coated with rhodium and can resist corrosion.*

Fibreglass production

These fibreglass strands *are made by passing molten glass through rhodium-enriched trays.*

The rosy red colour of one of its compounds inspired the name rhodium. The Greek word *rhodon* means "rose-coloured". Rhodium is unreactive and does not form compounds easily. It is a rare metal. Most of the **pure form** is extracted when platinum is mined. Pure rhodium is hard and is used to toughen precious **jewellery**, mirrors, and optical devices, such as **microscopes**. It is mainly used in the production of catalytic convertors for cars. **Fibreglass**, which is often found in protective gear – like helmets – also contains rhodium.

46
Pd
Palladium



46 46 60
State: Solid
Discovery: 1803

Forms

The mines in this area have a high concentration of palladium.

Blue Ridge mines, South Africa

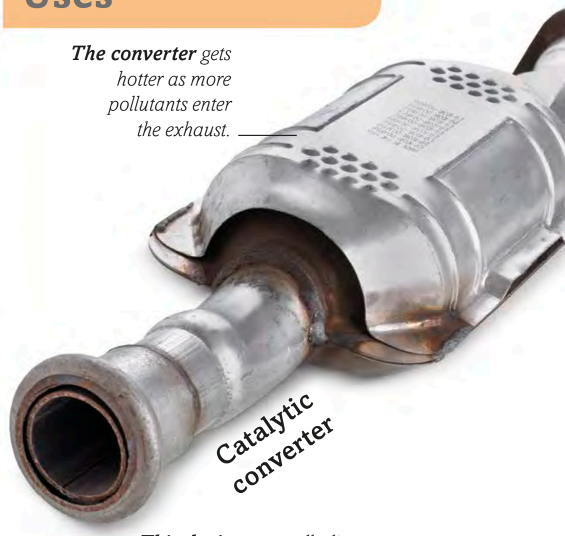
Palladium absorbs **hydrogen**, like a sponge soaking up water.

Pure form can be produced by separating it from the ores of other metals, such as copper and nickel.

Pure palladium pellet refined in a laboratory

Uses

The converter gets hotter as more pollutants enter the exhaust.



Catalytic converter

This device uses palladium compounds that change colour when poisonous carbon monoxide is detected, which triggers an alarm.

Carbon monoxide detector

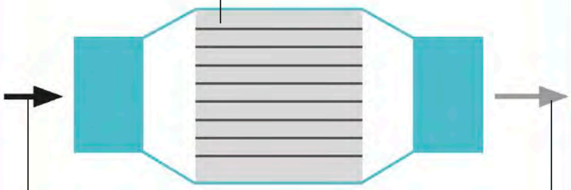
This commemorative coin is made from the palladium produced by the Stillwater Mining company in Montana, USA.

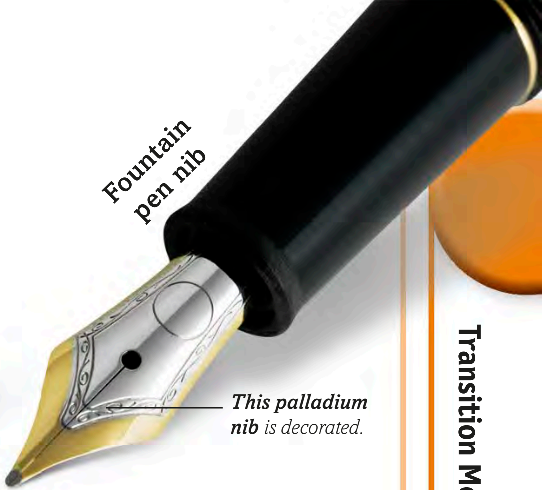
Palladium coin

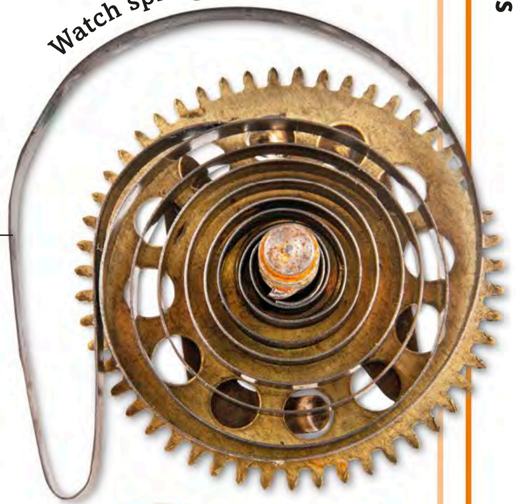
Palladium is a rare, precious metal: it is 10 times rarer than silver and twice as rare as gold. Like these metals, palladium has a shiny surface and does not corrode easily. Palladium is found **pure** in nature, but it also has a few rare minerals, such as braggite. Of its many applications, the element's main use is in **catalytic converters**, which are devices used in vehicles to convert poisonous exhaust gases into less harmful ones. A compound called palladium chloride is used in **carbon monoxide detectors**. Because the element is

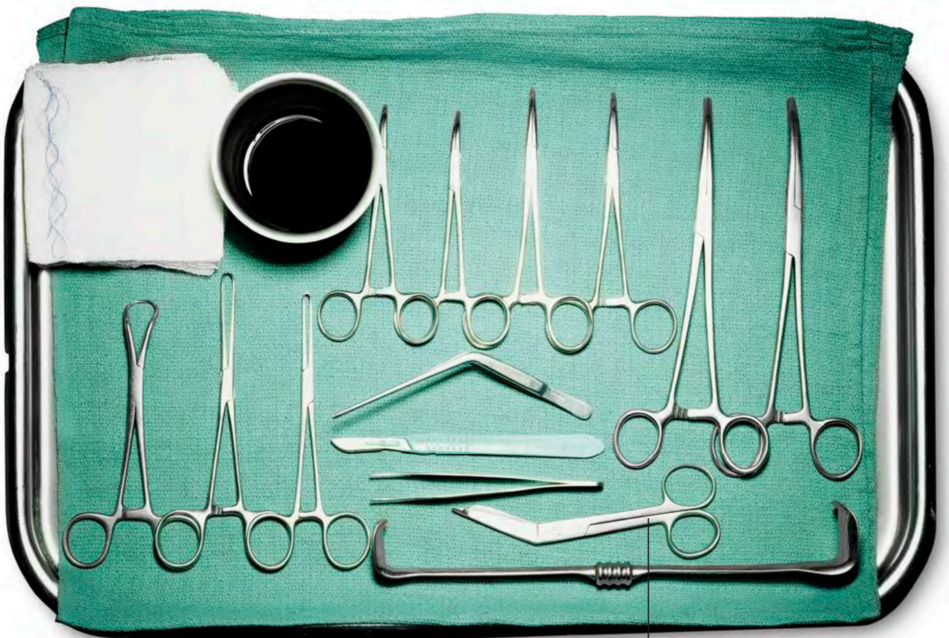
CATALYTIC CONVERTER

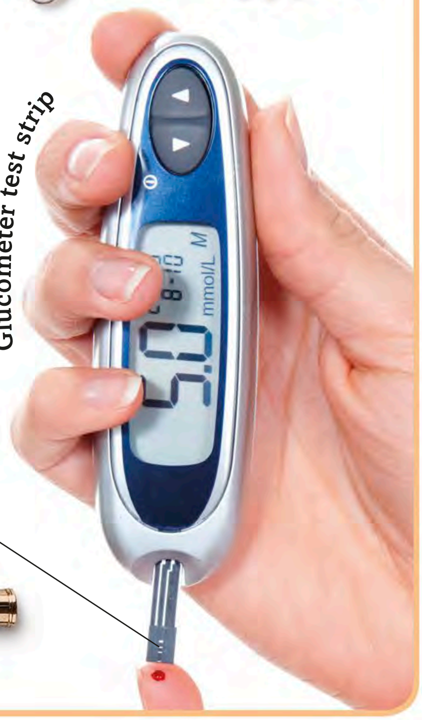
Many cars contain engines that are attached to catalytic convertors. These important devices convert toxic exhaust gases into less harmful pollutants. Palladium plays a key role in the process.





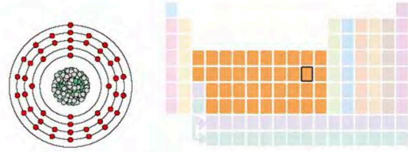






precious, it is used to make **commemorative coins** in some countries. Palladium is alloyed with steel to make it more resistant to corrosion. These alloys are used to make **surgical tools** and expensive musical instruments, such as some **flutes**. Palladium is often mixed with gold to form an alloy called white gold, which is used in jewellery. Some fountain pens have **nibs** decorated with palladium. The element is also used in **glucometer test strips** so that patients can check the level of glucose in their blood.

47
Ag
Silver



47 47 61
State: Solid
Discovery: c. 3000 BCE

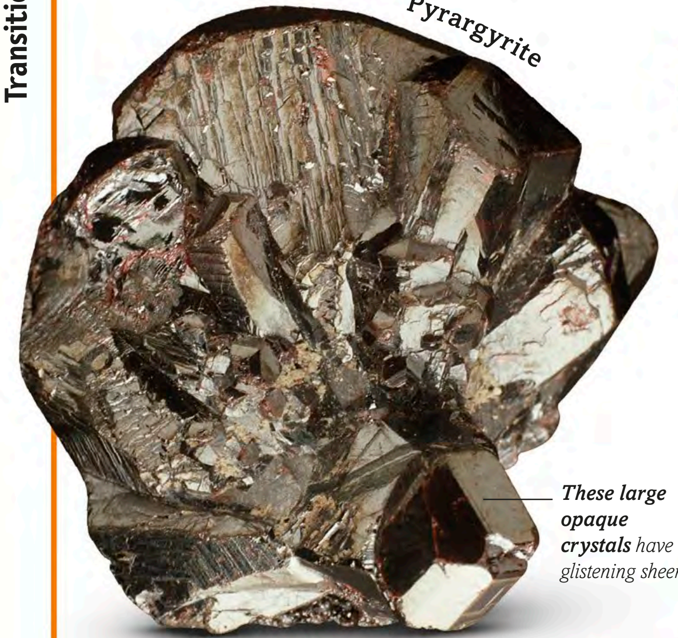
Transition Metals

Forms

Chlorargyrite

***This mineral's colour** changes to purple when it is exposed to bright light.*

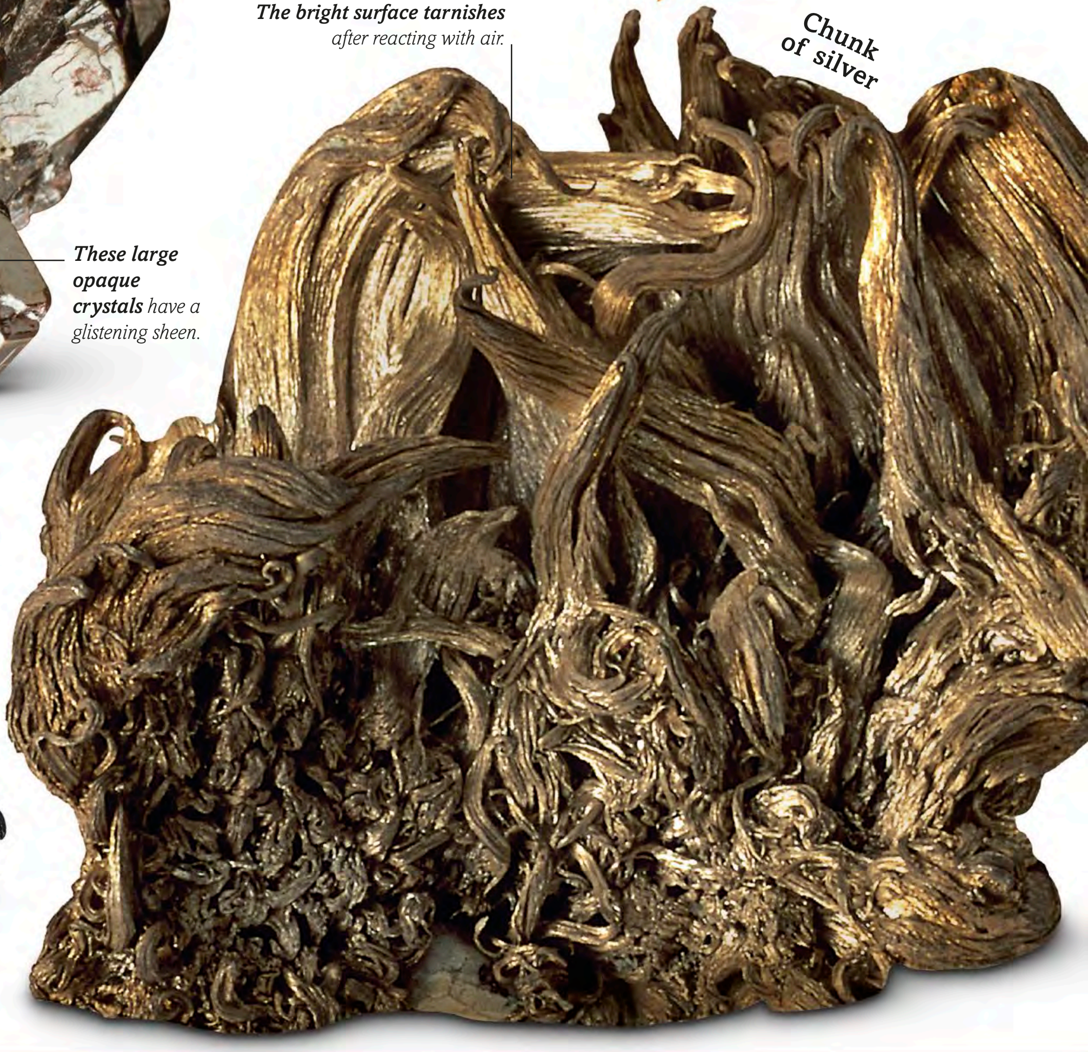
Pyrargyrite



***These large opaque crystals** have a glistening sheen.*

1 g (0.03 oz) of silver can be drawn into a **2-km- (1.2-mile-) long** wire.

Chunk of silver



***The bright surface tarnishes** after reacting with air.*

Acanthite

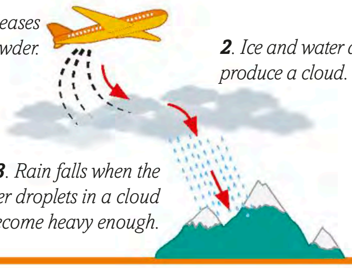
***Black silver sulfide** forms twisted crystals.*

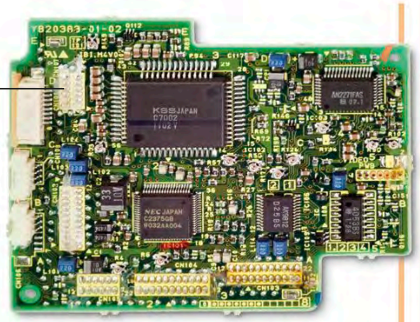
Silver gets its symbol "Ag" from its Latin name *argentum*, which means "shiny white". It is considered a precious metal because its pure form has a grey shine that does not corrode quickly, and it stays untarnished if cleaned regularly. Silver can be found pure in nature, but mostly it is mined from ores, such as **pyrargyrite** and **acanthite**. Because this element is valuable and can be moulded easily, pure silver was used historically to make **coins**. This metal is also ideal for making **bracelets** and settings for gems. Some people even use

Uses

MAKING CLOUDS

Rain is crucial to our Earth, especially for growing healthy crops. Where there are no clouds, scientists can form tiny water droplets that cling to silver iodide powder, forming artificial rain clouds.





***Silver coating** is used on some circuit board parts.*

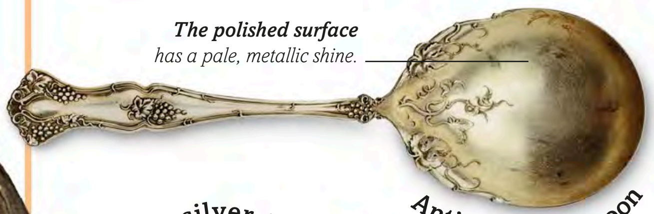
Circuit board

Silver coin

***Soft silver** is easily pressed into coins.*

Silver bracelet

***Pure silver** moulded and cut into varying shapes*



***The polished surface** has a pale, metallic shine.*

Antique silver spoon

Edible silver foil

***These thin sheets of silver** called "vark" are edible.*

***Silver nitrate** is mixed with water to clean cuts and scrapes.*

Silver nitrate

***Glass infused with silver chloride** turns brownish when exposed to sunlight.*

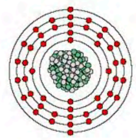
Photochromatic glasses

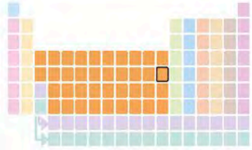
Photography plate

***An image forms** when silver bromide darkens quickly on exposure to light.*

flattened **silver foil** to decorate food. **Silver spoons** and forks were the only pieces of cutlery that did not create a nasty metallic flavour in the mouth in the days before the invention of stainless steel. Silver conducts electricity better than copper, and is used in some **circuit boards**. **Silver nitrate** (a compound of silver, nitrogen, and oxygen) is a mild disinfectant used in some anti-bacterial soaps. Silver forms light-sensitive compounds with chlorine (used in **sunglasses**) and bromine (used in old **photography plates**).

48
Cd
Cadmium

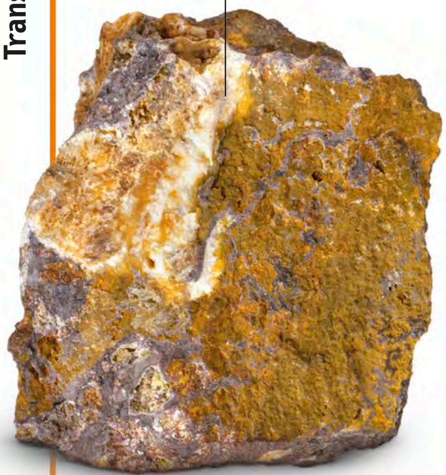




48 48 64
State: Solid
Discovery: 1817

Forms

***This mineral** contains a rare form of cadmium sulfide, a compound of cadmium and sulfur.*



Greenockite

***This soft metal** has a bluish tinge.*

Pellet of pure cadmium refined in a laboratory

***The yellow colour** of this zinc mineral is due to cadmium impurities.*

Smithsonite

Uses

Nickel-cadmium battery

***Cadmium and nickel layers** create electricity in this rechargeable battery.*

***This deep red pigment** contains powdered cadmium oxide.*

Red paint containing cadmium

***This electronic component** used in circuits contains a compound of cadmium and sulfur.*

Light-sensitive resistor

***Cadmium-covered screws** do not rust.*

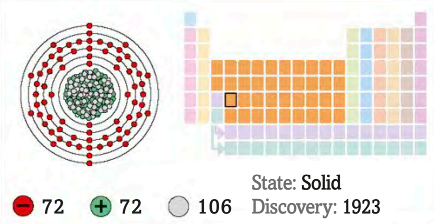
Cadmium-plated screws

***This research sample** is being viewed under ultraviolet (UV) light produced by a cadmium laser.*

Fluorescent microscope

Cadmium is a highly toxic metal, and is known to cause cancer. This rare element is found in the ore **greenockite**, but it is mostly obtained as a by-product of zinc extraction. **Cadmium** was discovered in 1817 from a mineral called calamine. Today, this metal is mainly used in conjunction with nickel in **rechargeable batteries**. The compound cadmium oxide was once used in preparing **red paints**, but not anymore because of its toxicity. Cadmium is also used to create lasers for use in powerful **microscopes**.

72
Hf
Hafnium



State: Solid
Discovery: 1923

Forms

Zircon crystals

***Hafnium** uses up 4% of the mass of this zircon crystal.*

A zircon crystal can be up to **4 billion years** old.

Laboratory sample of pure hafnium

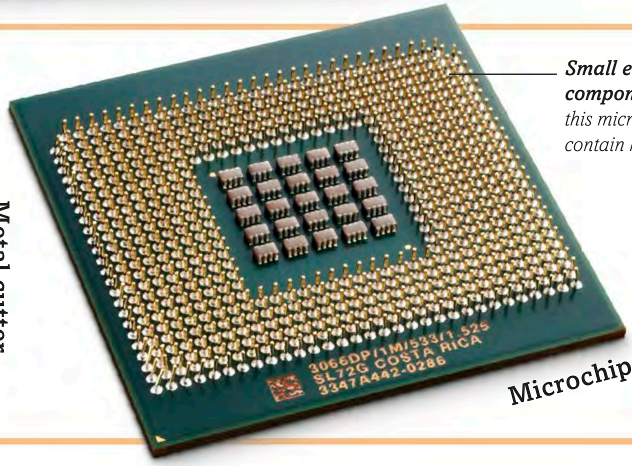
***This element's pure form** is resistant to corrosion in air.*

Uses

***Sections of this cutter** are made of hafnium.*

Metal cutter

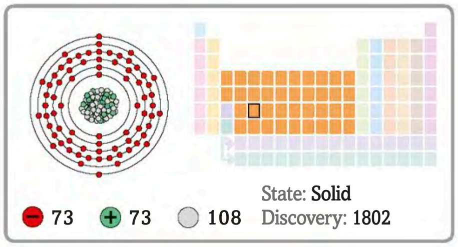
***Small electronic components** in this microchip contain hafnium.*



Microchip

Hafnium is named after *Hafnia*, the Latin word for the city of Copenhagen in Denmark. It took a long time to distinguish hafnium from zirconium because the two elements are present together in crystals of the mineral **zircon** and their atoms are similar sizes. Hafnium is used in powerful **cutters** that pierce metallic objects with a hot stream of sparks. It is also used to make ultra-small electronics – only a few millionths of a millimetre wide – in **microchips**.

73
Ta
Tantalum

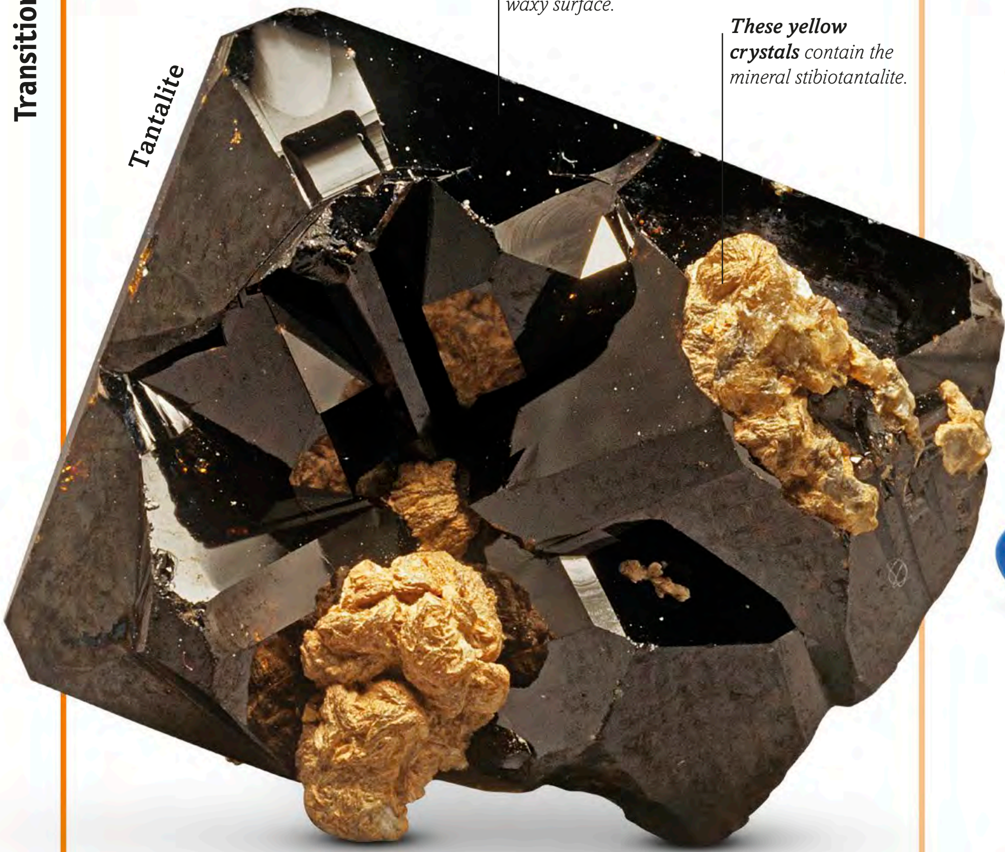


Forms

Tantalite

The mineral has a dark, waxy surface.

These yellow crystals *contain the mineral stibiotantalite.*



The pure metal *barely reacts with air, so stays shiny.*

Rods of pure tantalum refined in a laboratory

Uses

Artificial joint

The tantalum shell *of this hip implant is lightweight and flexible.*

Tantalum capacitors *are used to store a lot of electric charge in small circuits, such as the ones inside mobile phones.*

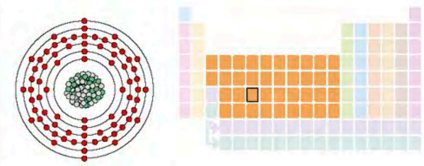
Electronic capacitor

Metallic watch

The case and strap of this watch *are made of an alloy of tantalum, gold, and copper.*

Tantalum is a hard metal named after Tantalus, a man from Greek mythology who was punished by the gods. It is extracted from a rare mineral called **tantalite**. This tough metal is not harmful to the human body, so it is used to make **artificial joints** and other body implants. Tantalum powder is used in **capacitors** – devices used in electronic circuits to store electricity. This strong metal toughens **watches** made of softer, precious metals. Tantalum is also used to create strong turbine blades that do not corrode.

74
W
Tungsten



74 74 110
State: Solid
Discovery: 1783

Forms

This dark, metallic mineral *contains tungsten and iron.*

Ferberite

This mineral *is the main source of pure tungsten.*

Wolframite

Pure tungsten *is a hard, grey metal.*

Cylinder of pure tungsten refined in a laboratory

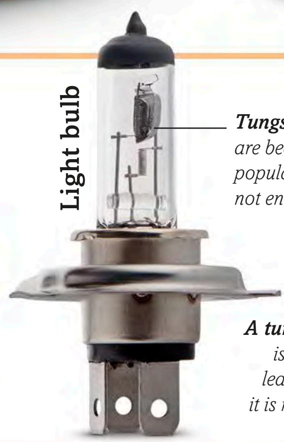
Uses

Drill bit

This drill bit *has a coating of tungsten carbide, which protects it from damage.*

Tungsten pigments were in use in Chinese porcelain 350 years ago.

Light bulb



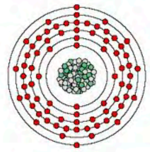
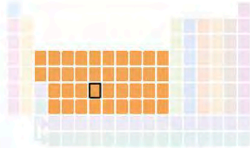
Tungsten filaments *are becoming less popular as they are not energy-efficient.*

Fishing sinker

A tungsten sinker *is preferred to a lead one because it is not poisonous.*

Tungsten has the highest melting point of any metal: it turns to liquid at a searing 3,414°C (6,177.2°F). It is a very dense metal, and its name comes from the Swedish phrase for "heavy stone". This metal is usually obtained from the mineral **wolframite**. A compound called tungsten carbide is used to harden objects such as **drill bits**. Tungsten's high melting point allows it to be used in the filaments of **light bulbs**. This element is also useful in producing weights, such as **sinkers** used with fishing lures.

75
Re
Rhenium

75 75 111

State: **Solid**
Discovery: **1925**

Forms

Molybdenite

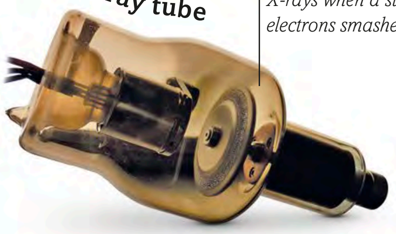
***This ore** contains molybdenum and small amounts of rhenium.*

Pure rhenium pellet

***Pure rhenium** is denser than gold.*

Uses

X-ray tube



***These tubes** contain a rhenium alloy that produces X-rays when a stream of electrons smashes into it.*

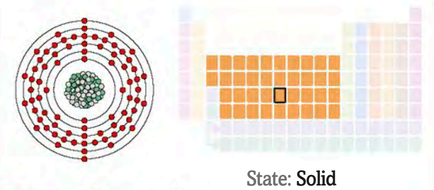
Rhenium has the **highest boiling point** of any element.

F-22 Raptor fighter plane

***This plane** has jet engines containing a heat-proof rhenium alloy.*

Rhenium is very rare in nature: only one atom out of every billion in Earth's crust is a rhenium atom. Discovered in Germany in 1925, and named after the Rhine river – it was the last stable, non-radioactive element to be found. Rhenium has a very high melting point, and can stay solid at extreme temperatures. This allows alloys made of this element to be used in very hot conditions, such as those inside the tubes of **X-ray machines**, as well those in the exhaust nozzles of rockets and the jet engines of **fighter planes**.

76
Os
Osmium



State: Solid
Discovery: 1803

Forms

Osmiridium sand

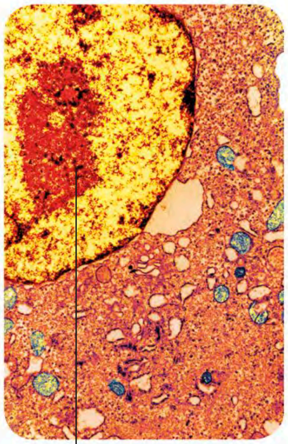
***This is a natural alloy** of osmium and iridium.*

Pellet of pure osmium refined in a laboratory

***The pure form** is hard but shatters easily.*

Uses

Transmission electron microscope (TEM) image



***Osmium oxide** is used to highlight objects inside a cell.*

Fingerprint powder in use

***Black osmium oxide powder** clings to oily fingerprints.*

Record player

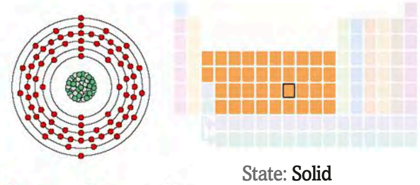
***The needle** of this old record player is made of osmium.*

Fountain pen

***The nib of this pen** moves smoothly because of its hardy osmium alloy.*

Osmium is the densest of all naturally occurring elements: 250 ml (8.5 fl oz) of this metal (in its liquid form) weighs 5.5 kg (12 lb). This rare element is found in the ore **osmiridium**. **Pure osmium** reacts with oxygen in the air to form a poisonous oxide, so the metal is used safely by combining it with other elements or alloys. A red osmium oxide stains cells so they can be seen clearly under a powerful **microscope**, while a black oxide powder allows **fingerprints** to be revealed in crime investigations. A hard osmium alloy is used in **fountain pen** nibs.

77
Ir
Iridium



77 77 115
State: Solid
Discovery: 1803

Forms

Pure iridium crystals

This metal *is 22 times as dense as water.*

These rocks *contain a layer of iridium-rich clay.*

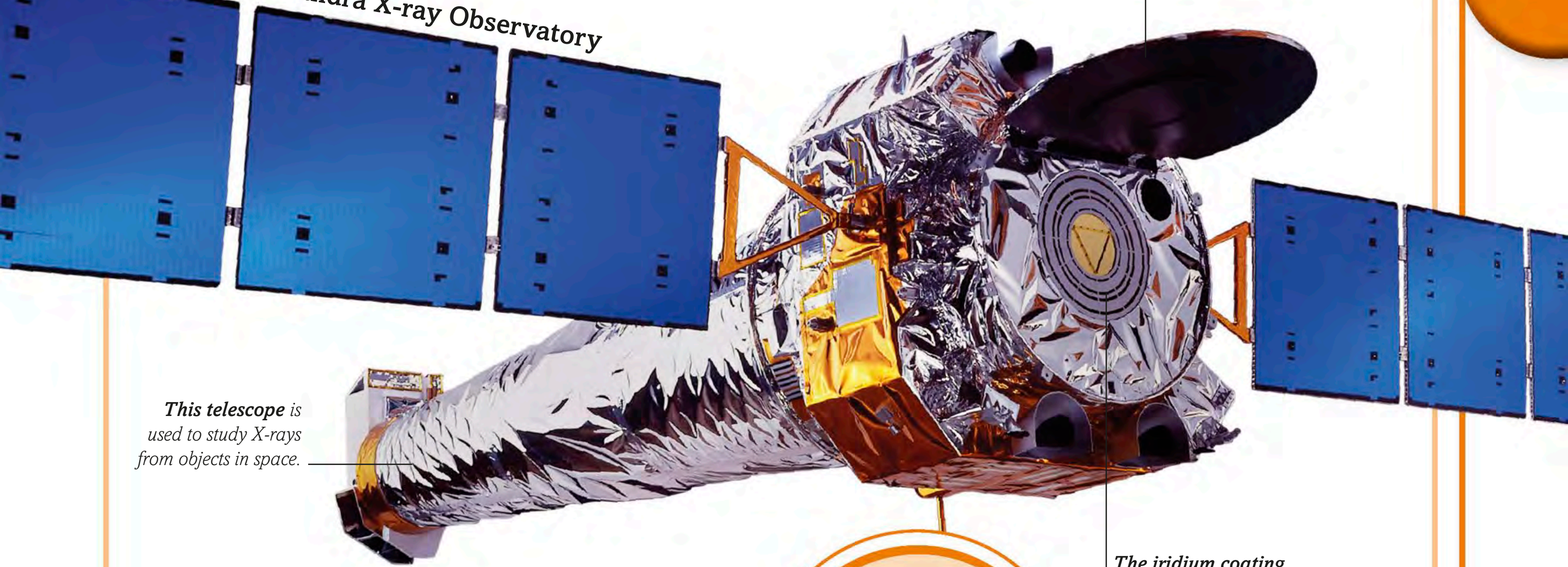
Badlands National Parks, South Dakota, USA

Willamette meteorite

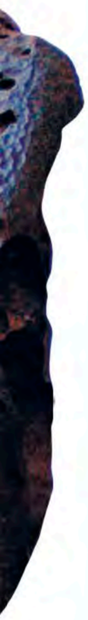
This meteorite, *found in Oregon, USA, contains just 0.00047% iridium.*

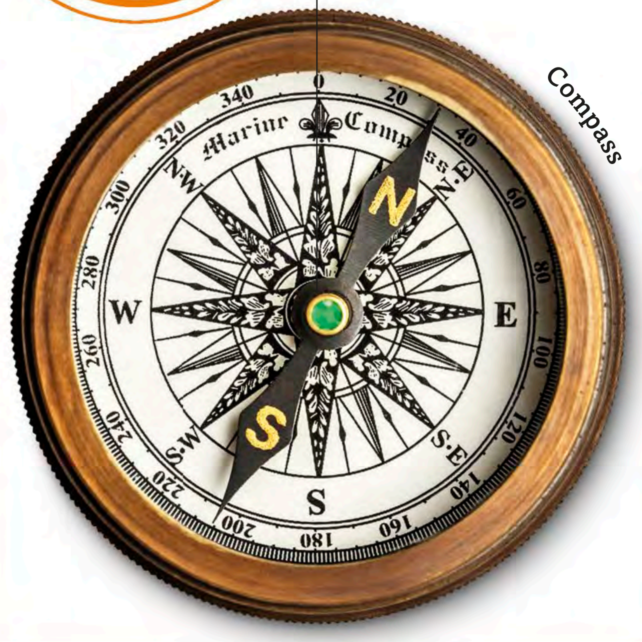
Iridium is the rarest natural element on Earth: there is one iridium atom out of every billion atoms in Earth's rocks. This dense metal can be found in its **pure** form in nature as well as in other common ores that contain nickel and copper. Iridium is present in **meteorites** and other space rocks. A layer of iridium-rich clay is found in Earth's crust all over the world, especially in the **Badlands of South Dakota, USA**. Scientists believe this small quantity of iridium in our planet's crust was deposited by the dust from an

Uses



Iridium is the **second densest metal**, after osmium.



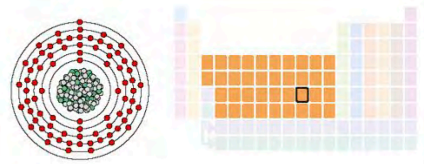


LUIS WALTER ALVAREZ

In 1980, the American physicist Luis Walter Alvarez and his son Walter discovered a layer of iridium-rich clay in rocks all over the world. They suggested that this was the result of a meteorite impact about 66 million years ago, which led to the extinction of the dinosaurs.

explosion 66 million years ago when a large meteorite hit our planet. The applications of this element include coating the mirror of NASA's **Chandra X-ray Observatory**, an Earth-orbiting telescope that studies X-rays from distant stars. Iridium is more durable than platinum and copper, and is therefore preferred over these metals for use in spark plugs. Iridium is also mixed with osmium to make an alloy called osmiridium, which is used in **compasses** and put in nibs for some fountain pens to make them hardy.

78
Pt
Platinum



78 78 117
State: Solid
Discovery: Unknown

Forms

This dense, shiny mineral *consisting of platinum and arsenic is the most common ore of platinum.*

Sperrylite

Platinum melts at the high temperature of **1,768°C** (3,214°F).

Large nuggets *of pure platinum are rare.*

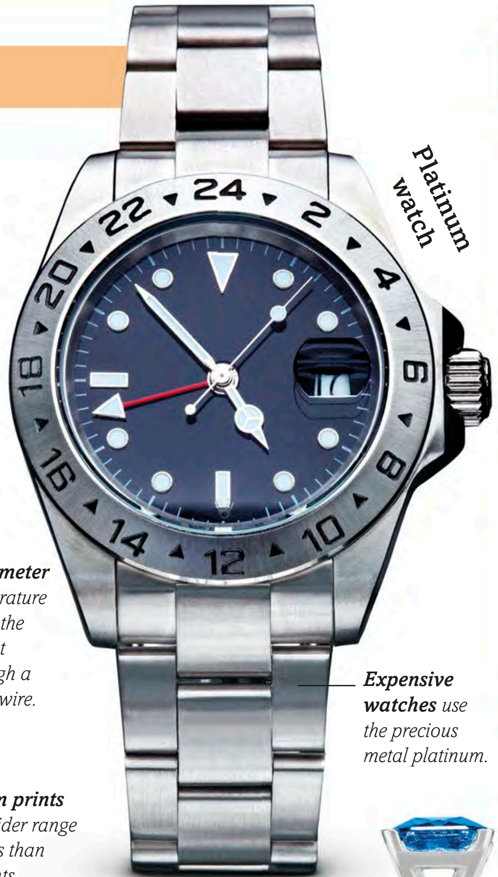
Nugget of pure platinum refined in a laboratory

Spanish explorers first found platinum in the mines of South America in the 1700s. They obtained a whitish substance that the locals living near there called *platina*, meaning "little silver". This precious metal has a silvery white shine. Platinum rarely reacts with other elements, even at high temperatures. This makes it difficult to extract from its ores, such as **sperrylite**. **Pure platinum** does not corrode or tarnish. It is, however, not easy to shape or mould, so use of platinum was limited to the making of simple jewellery and **watches**. By the 20th century,

Uses

Platinum resistance thermometer

This thermometer *records temperature by measuring the electric current flowing through a fine platinum wire.*

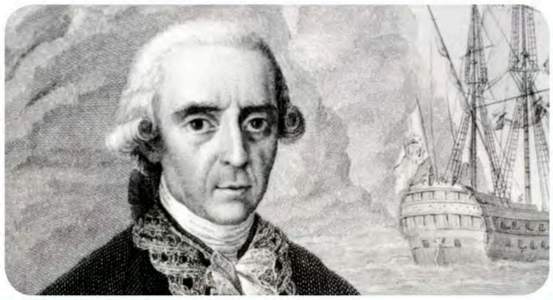


Platinum watch

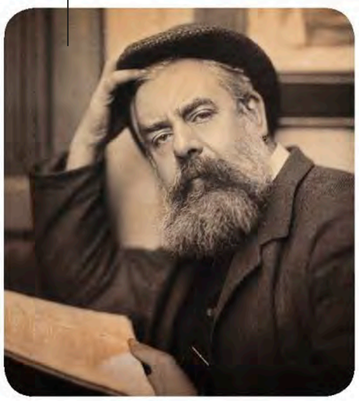
Expensive watches *use the precious metal platinum.*

ANTONIO DE ULLOA

Although platinum had been in use in jewellery on the west coast of South America for more than 2,000 years, it was Spanish naval officer Antonio de Ulloa who made the first major study of it. In 1735, while on a South American expedition, he found grains of the metal in river sands. He brought them back to Spain to examine them.



Platinum prints *have a wider range of shades than silver prints.*



Black and white photographic print

Platinum ring

Jewellery *made of platinum does not lose its shine.*

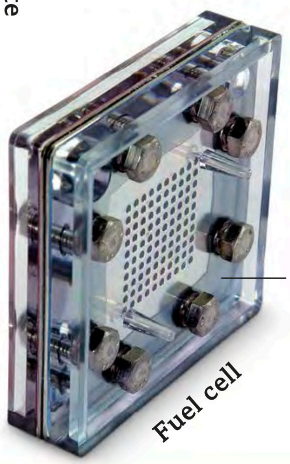
Dental fillings *once contained platinum and mercury.*

Dental crown

This drug *contains platinum and kills cancer cells in the body.*

Cancer drug

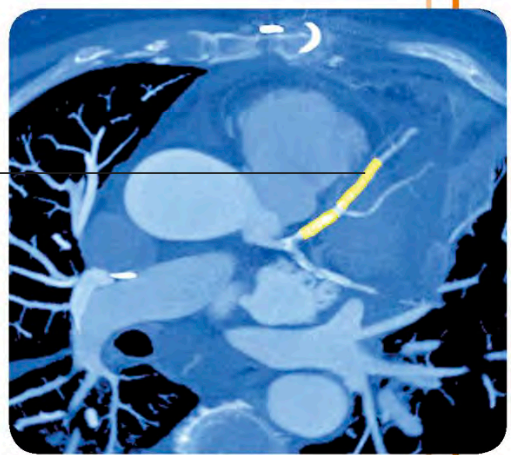
Platinum was found in an Egyptian casket from the **7th century BCE**.



Fuel cell

This fuel cell *contains platinum, which speeds up the reaction between hydrogen and oxygen.*

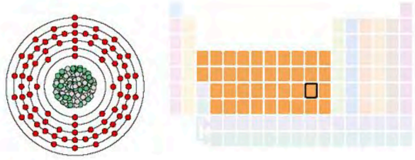
This stent made of platinum *is not harmful to the body and anchors a damaged blood vessel as it heals.*



Medical stent

more applications were discovered. Platinum can be used in place of silver to generate **photographic prints**, and in place of gold for making **dental fillings**. Today, platinum plays an important role in various technologies. For example, it is used in **fuel cells** – devices that generate electricity by combining hydrogen and oxygen. These cells do not need to be recharged like other batteries. Powerful **drugs for treating cancer** contain this element, while **stents** made of pure platinum help heal damaged blood vessels.

79
Au
Gold



79 79 118

State: Solid
Discovery: c. 3000 BCE

Forms

Gold's chemical symbol **Au**, comes from its **latin name**, *aurum*.

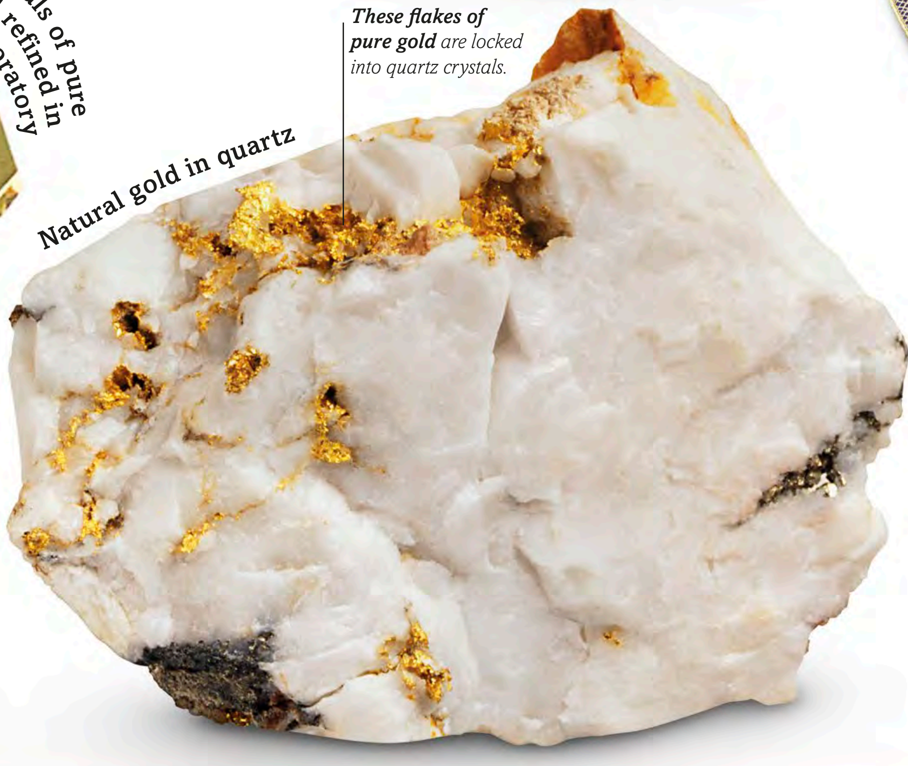
Pure gold has a dark yellow colour unlike any other metal.

These crystals may be elongated, rectangular, or cubic.

Crystals of pure gold refined in a laboratory

Calaverite

This mineral ore contains gold and tellurium.



These flakes of pure gold are locked into quartz crystals.

Natural gold in quartz

People were making gold ornaments more than 6,000 years ago. This was many centuries before they learned how to purify copper, iron, and other metals. Gold is believed by many to be the first metal element to be identified. It is a dense, unreactive metal with a distinctive deep yellow colour. Gold is naturally **pure** and seldom makes compounds in nature; the compound in the mineral ore **calaverite** is an exception. **Pure gold** found in nature may form nuggets but mostly is found as tiny specks embedded in rocks. Gold miners crush up these rocks and wash out the

Uses

This very thin layer of ***gold*** *protects the astronaut from the Sun's heat.*

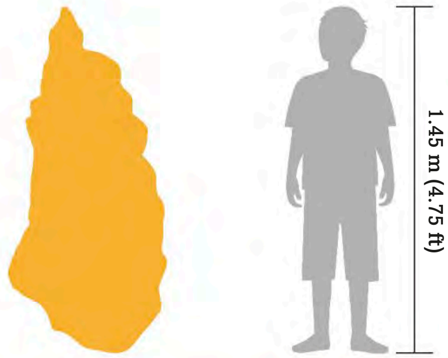
Astronaut's visor

This mask was placed over the pharaoh's mummified face.

Tutankhamun's death mask

THE HOLTERMANN NUGGET

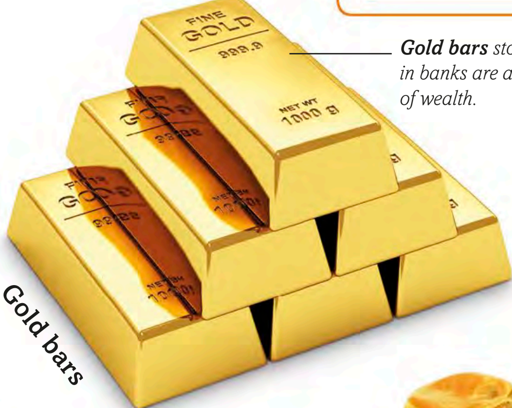
The largest piece of natural gold was found on 19 October, 1872, near the small town of Hill End in Australia. Named after its discoverer, Bernhardt Holtermann, the piece contained moe than 90 kg (198 lb) of pure gold.



Holtermann Nugget **Child aged 10 years old**

Royal Crown Derby plate

This glass plate contains specks of gold.



Gold bars

Gold bars *stored in banks are a sign of wealth.*

Edible gold flakes

The flakes *decorating this expensive chocolate are edible.*

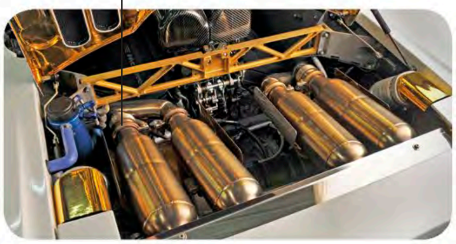
Gold teeth

These replacement teeth *are made of gold and mercury.*

Wat Phrathat Doi Suthep temple, Thailand

A thin layer of gold *covers this entire temple.*

Gold foil *keeps this car engine at a stable temperature.*



McLaren F1 car engine

Ancient gold jewellery

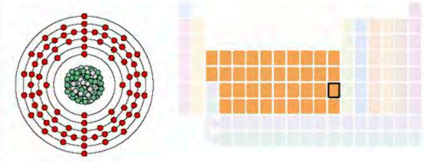
This neck ornament *is made from cast gold.*

gold dust with water or strong acids. The applications for gold include heat shields in **astronaut's visors**. This metal has always been seen as valuable and many ancient artefacts, such as the **3,300-year-old death mask** of Egyptian pharaoh Tutankhamun, were forged from it. Some of the earliest coins, found in Turkey, were made of it. Gold is used to cover important buildings, such as Thailand's **Wat Phrathat Doi Suthep** temple. This precious metal is most commonly used today in **jewellery** or decorations.

GOLDEN BUDDHA A precious statue of Buddha with one thousand eyes and one thousand hands stands in Long Son Pagoda, a temple in Nha Trang, Vietnam. The Buddha is depicted as holding a range of sacred objects, including scrolls and white lotus flowers. This statue is completely covered in a layer of pure gold, and it draws in hundreds of devotees from across the world.

Although humans have discovered many strong metals and useful elements, gold has remained one of the most valuable. Before people knew what it was, they saw glittering gold dust in river beds or dug large gold nuggets out from rocks. They found that gold has many valuable qualities: it is soft enough to hammer into any shape and can be melted down for moulding into ornaments. Best of all, its gleaming golden colour never fades away. Ancient cultures prized items made of gold: in ancient Egypt, gold was used to make coins as well as to cap the tops of pyramids. Gold is, however, so rare that if all the world's mined gold were forged into a cube, it would fit inside the penalty area of a soccer pitch.

80
Hg Mercury



80 80 121
State: Liquid
Discovery: c. 1500 BCE

Forms

Solid mercury is soft enough to be **cut with a knife**.

Mercury is the only metal that is liquid at room temperature. Along with water, it is one of the few liquids found naturally on Earth's surface. **Pure mercury** forms around volcanoes where the heat separates it from its minerals, such as **cinnabar**. This red mineral has been used for many centuries: ancient Romans roasted cinnabar to release a liquid they called *hydrargyrum*, meaning "silver water". This was the element mercury. It was later known as quicksilver because of how fast it flowed as a stream of liquid. This metal is very poisonous:

Uses

This thermometer *contains mercury, which expands as it gets warmer and contracts as it cools.*

Mercury thermometer

Pills containing mercury *were commonly used to treat constipation and toothache.*

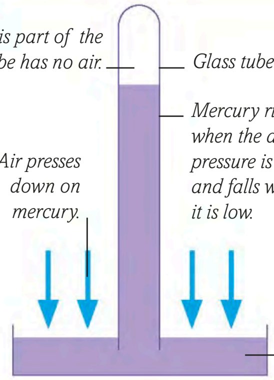
Mercury pills

This bulb *glows when the mercury vapour inside it is electrified.*

CFL bulb

Mercury has been in use for more than **4,000 years**.

HOW DOES A BAROMETER WORK?



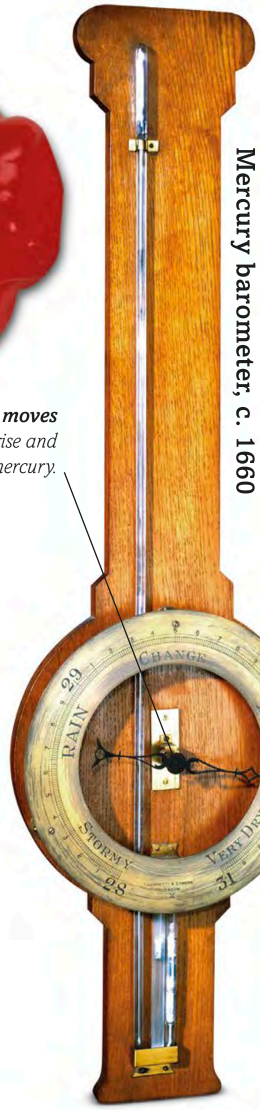
A barometer is an instrument used to measure air pressure to forecast the weather. The simplest – and earliest – designs used a column of mercury inside a glass tube.

This bright red paint *is made with powdered cinnabar.*

Red paint

This large, low-cost mirror *made of a pool of pure mercury is used in an astronomical telescope.*

Liquid mirror inside telescope

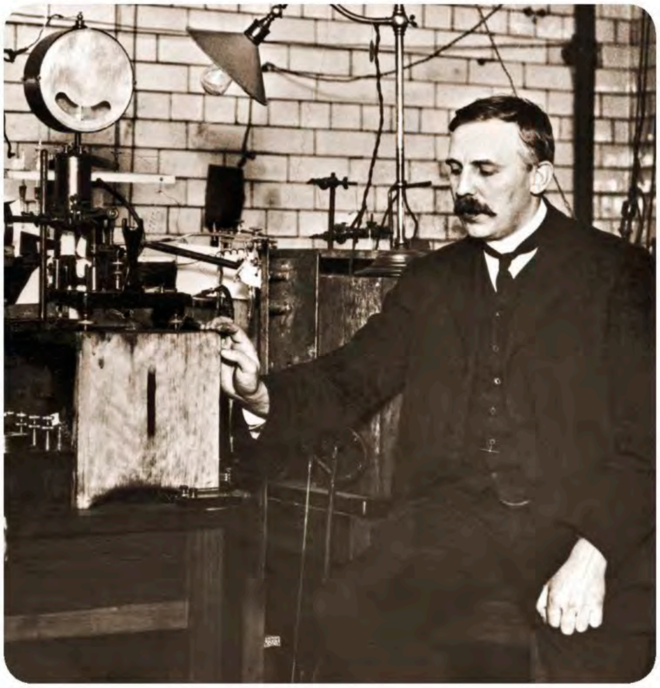


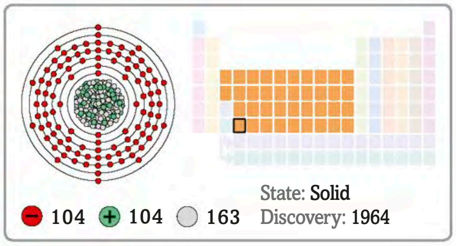
The needle moves *with the rise and fall of mercury.*

Mercury barometer, c. 1660

it can damage organs and nerves if inhaled or swallowed. As a result, the use of this metal is carefully monitored today. Mercury is used in some batteries, some **thermometers**, and in low-energy, **compact fluorescent light (CFL) bulbs**. Its compounds are used to prepare strong, **red paints**. Until the early 18th century, mercury was used in **pills** for treating some common ailments. It gradually fell out of use when it was found to be toxic. The first accurate **barometers** also contained this liquid, but such devices are rarely seen today.

104
Rf
Rutherfordium


Ernest Rutherford

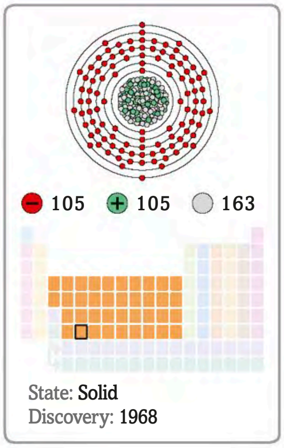


Rutherfordium was the first superheavy element to be discovered. In this type of element, each atom has 104 or more protons in its nucleus. It is named after the New Zealand scientist **Ernest Rutherford**, who, in 1913, suggested that every atom has a nucleus, or core. Pure rutherfordium is synthesized by researchers in a laboratory.

105
Db
Dubnium

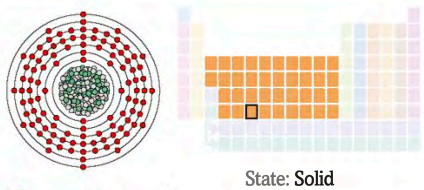

Albert Ghiorso

The US scientist Albert Ghiorso discovered **12 elements** in the 20th century.



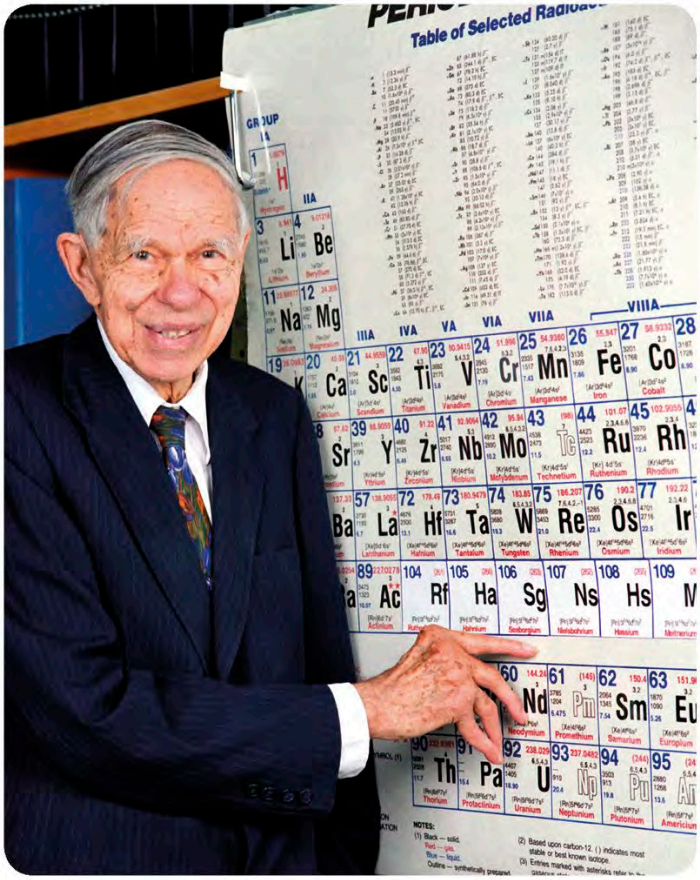
It took scientists nearly 30 years to agree on a name for this element. Dubnium was finally named after the Russian city of Dubna, where the first atoms of this artificial, radioactive element were created, in 1968. However, a team of American scientists led by **Albert Ghiorso** also produced samples of the element at the same time. This radioactive element has 12 isotopes, or forms, with different numbers of neutrons.

106
Sg
Seaborgium



106 106 163
State: Solid
Discovery: 1974

Atoms of seaborgium break apart in about three minutes, so little is known about it. Scientists think it may be a metal. The element was isolated in 1974 in a machine called the **Super Heavy Ion Linear Accelerator** at the Lawrence Berkeley National Laboratory. It was named after the US scientist Glenn T Seaborg.



Glenn T Seaborg

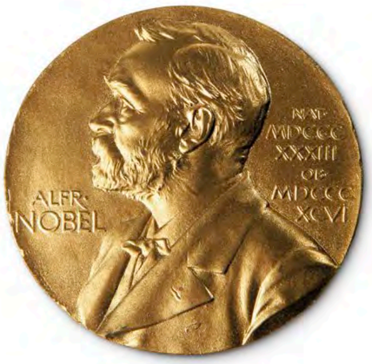
This huge machine was used to discover **five new elements**.

This giant tube *forms part of the Super Heavy Ion Linear Accelerator, which is a type of particle accelerator – a machine in which atoms are smashed together.*

Super Heavy Ion Linear Accelerator, Lawrence Berkeley National Laboratory, California, USA

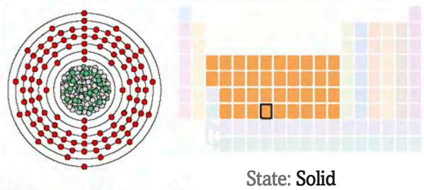
NOBEL PRIZE IN CHEMISTRY

Glenn T Seaborg and his fellow US researcher Edwin McMillan were awarded the Nobel Prize for Chemistry in 1951 for their work in creating neptunium. This was the first element to be isolated that was heavier than uranium – the heaviest natural element.



Nobel Prize medal

107 Bh Bohrium



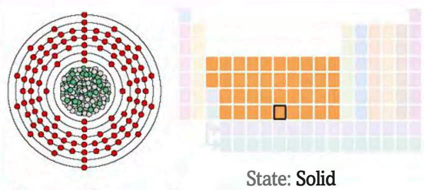
107 107 163

State: Solid
Discovery: 1981

Niels Bohr

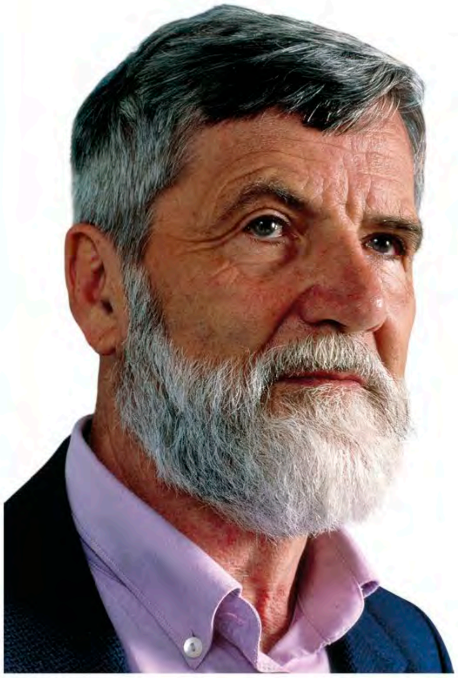
Bohrium is an artificial element named after the Danish scientist Niels Bohr. This was to honour his model of the structure of atoms' electron shells. Bohrium was first produced by firing chromium atoms at bismuth atoms in a particle accelerator (a machine in which atoms are smashed together). Atoms of this metal are unstable: half of any sample of bohrium atoms breaks apart in 61 seconds. As a result, it is not very well understood.

108 Hs Hassium



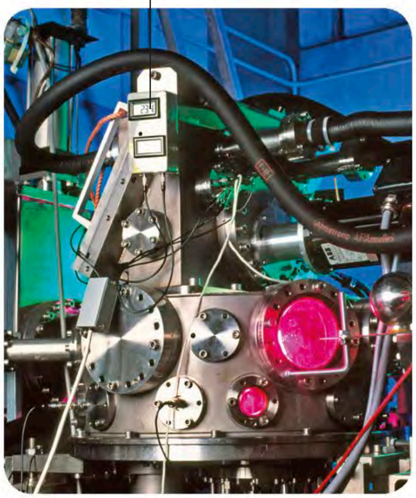
108 108 169

State: Solid
Discovery: 1984



Peter Armbruster

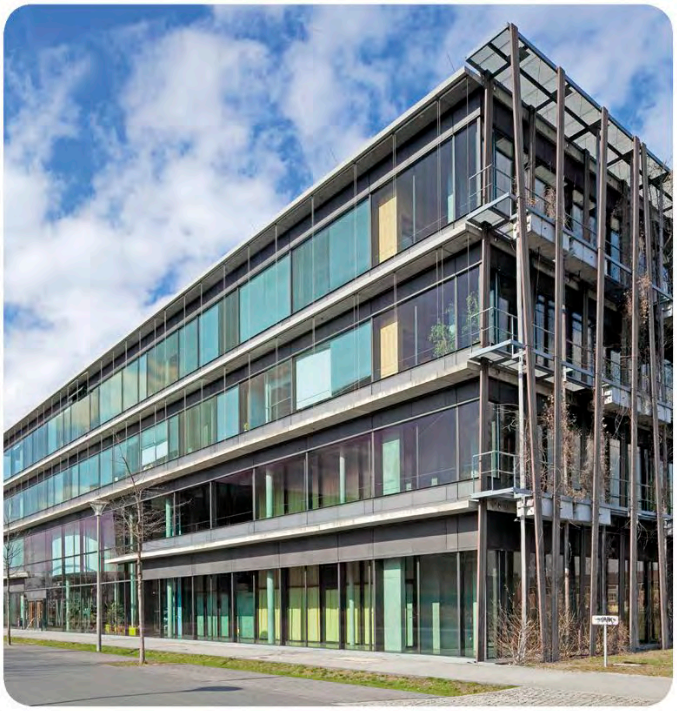
__Hassium__ was produced inside this chamber.



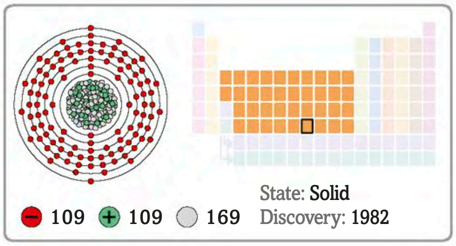
A chamber at Centre for Heavy Ion Research, Darmstadt, Germany

Scientists think hassium is a metal, but they have not been able to produce enough of its atoms to study it in any detail. Hassium is very radioactive, and most of its atoms break apart within a few seconds. This element is named after the German state of Hesse, the location of the **Centre for Heavy Ion Research**, where hassium was first created artificially by a team led by the German physicist **Peter Armbruster**.

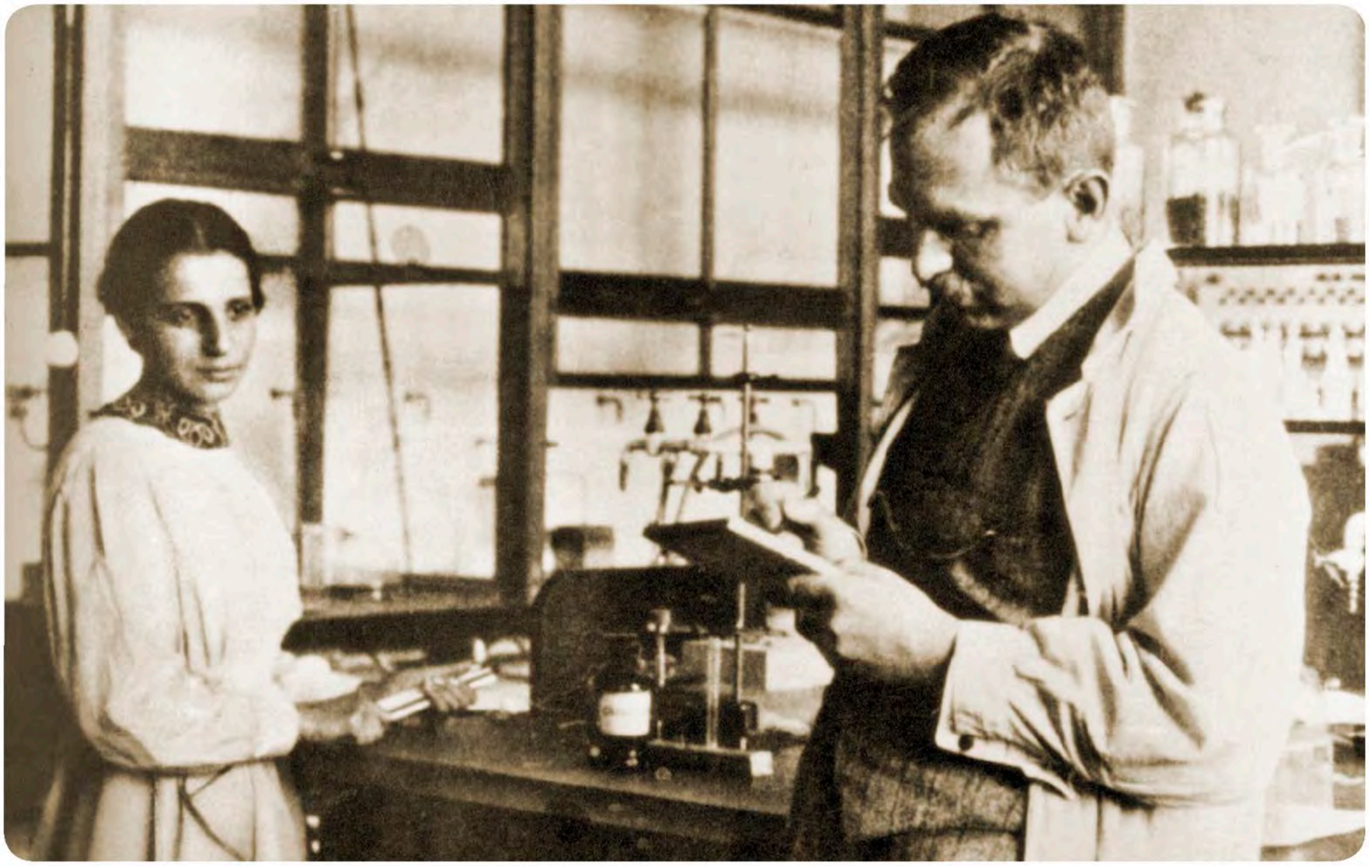
109 Mt Meitnerium



Meitner Haus building,
Humboldt University, Germany

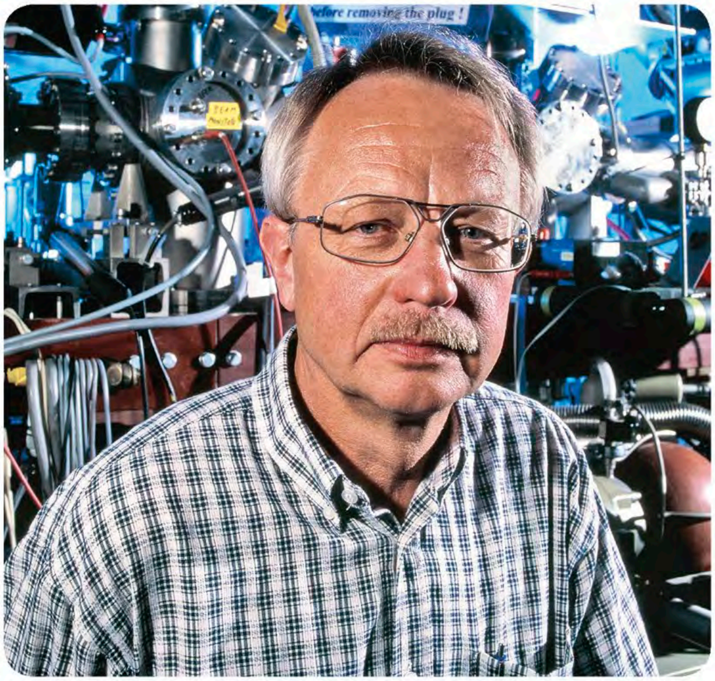


Researchers think meitnerium might be the densest of all elements. It is very unstable, and even the atoms of its most stable isotope, or form, break apart in a matter of seconds. Meitnerium is named after the Austrian physicist **Lise Meitner**, to honour her achievements in physics. Several universities, such as **Humboldt University** in Berlin, Germany, also have buildings in her name.

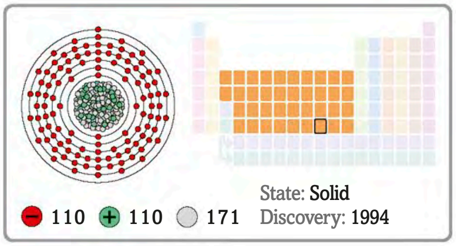


Lise Meitner (left) works with the German chemist Otto Hahn

110 Ds Darmstadtium



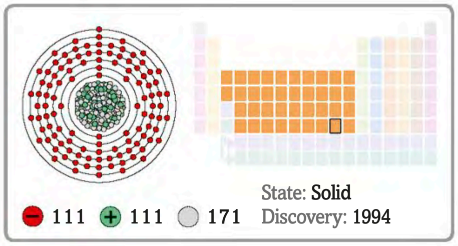
Sigurd Hofmann



This artificial element is named after the German city of Darmstadt – the home of the Institute for Heavy Ion Research where this element was first produced. A team led by the German physicist **Sigurd Hofmann** created darmstadtium by smashing nickel atoms into lead atoms in a particle accelerator (a machine in which atoms are smashed together).

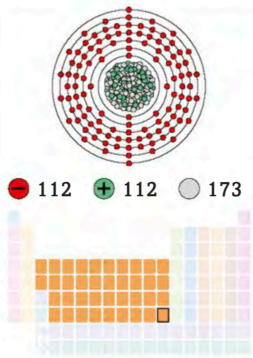
111 Rg Roentgenium

Wilhem Röntgen



Scientists believe that this metal shares many characteristics with precious metals, such as gold and silver. However, its atoms break apart within seconds, so this has not yet been confirmed. Roentgenium was created in Darmstadt, Germany. It was named after **Wilhelm Röntgen**, the German scientist who discovered X-rays in 1895.

112 Cn Copernicium



State: Solid
Discovery: 1996

Some scientists think copernicium could be the **only gaseous metal**.

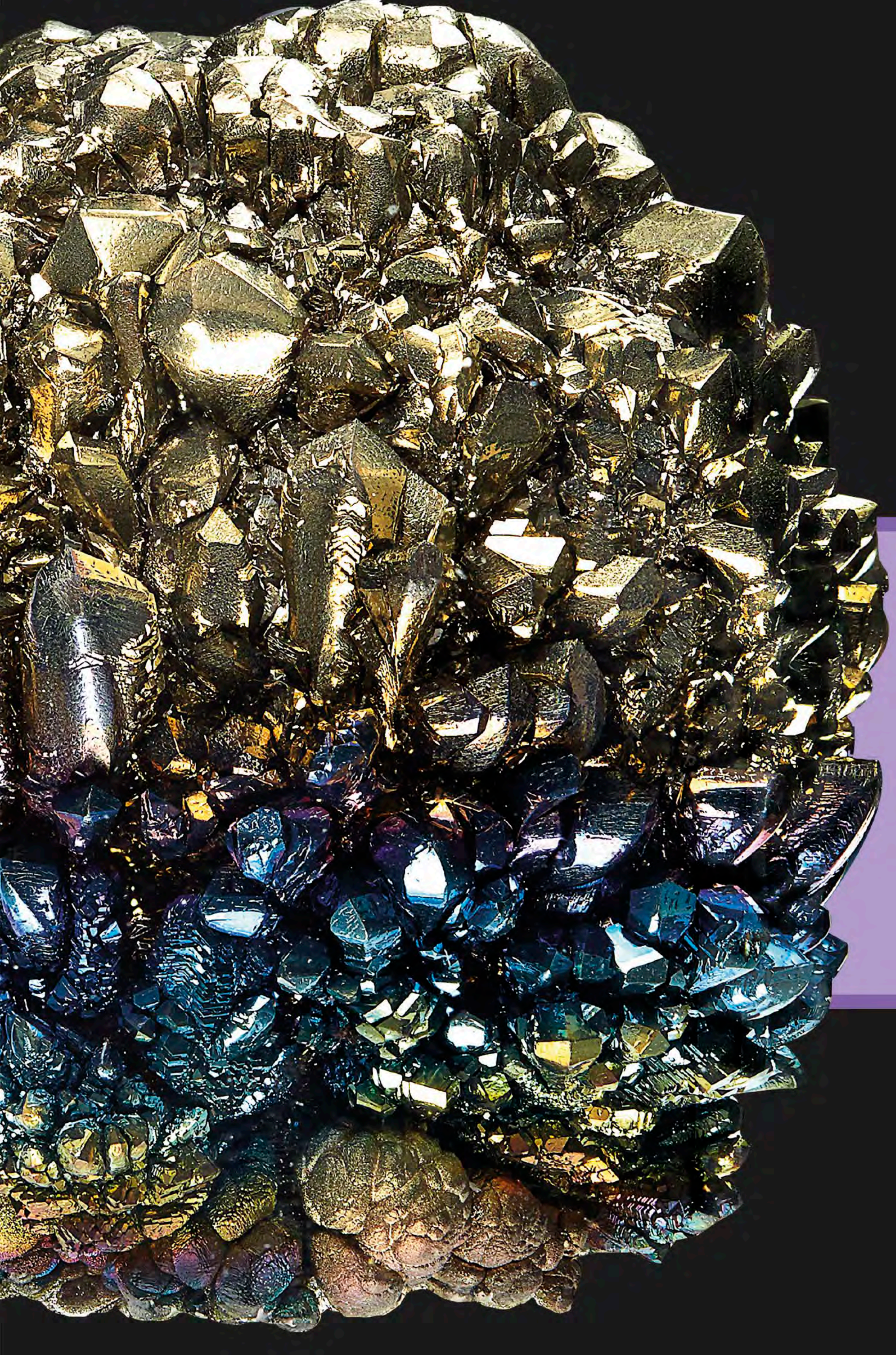
This statue *stands in front of the Polish castle in which Copernicus lived.*

Statue of Nicolaus Copernicus

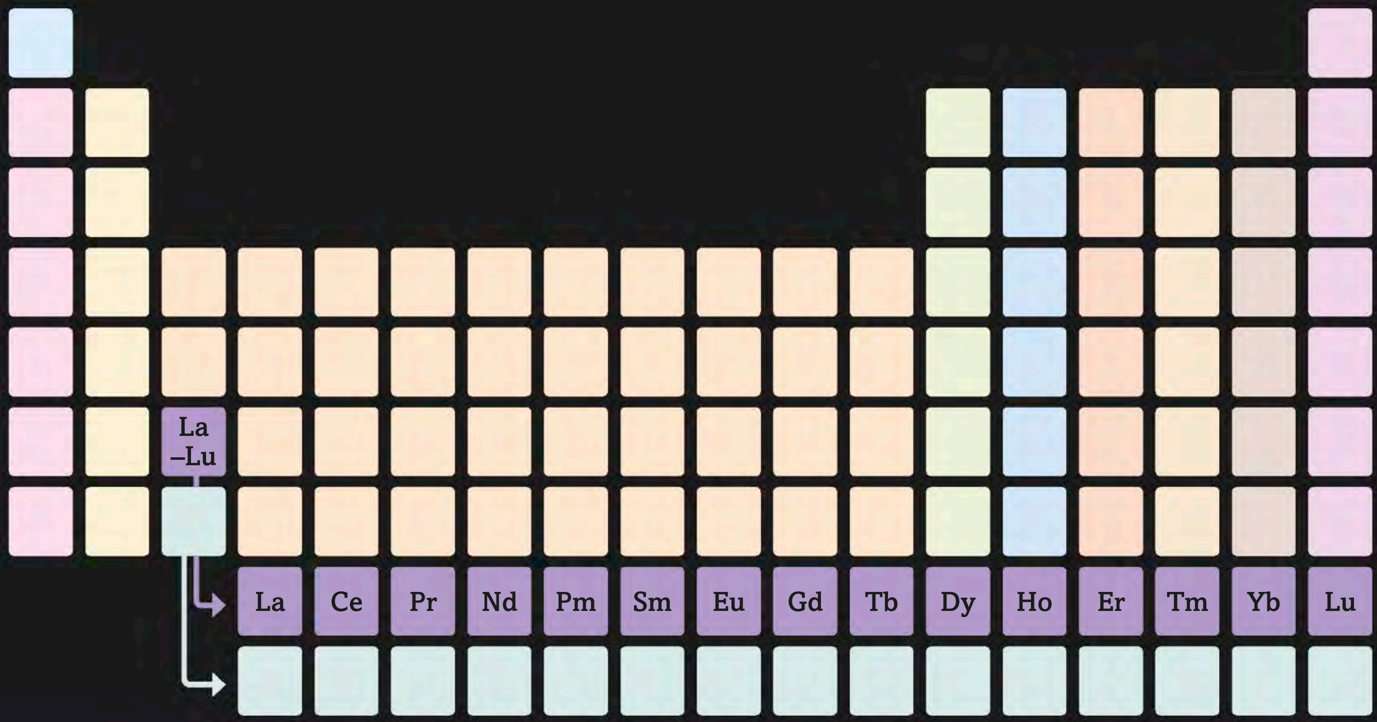
This German research institute *is where copernicium was discovered.*

Heavy Ion Research Centre, Germany

The atoms of this radioactive element survive only for a few minutes, before breaking down. Copernicium is created in particle accelerators by smashing together atoms of lead and zinc. Only a few atoms of this artificial element have ever been produced. Copernicium is named after **Nicolaus Copernicus**, the Polish astronomer who theorized that our planet orbits the Sun.



Europium's (Eu) colour changes when left in the air.



Lanthanides

This set is named after lanthanum, the first element in this series. The name “rare earth metals” is also given to these elements because they were discovered mixed together in complex minerals in Earth’s crust, and were thought to be uncommon. However, they are actually not rare but abundant. These metals – between barium (Ba) and hafnium (Hf) – should fit between the alkaline earth metals and the transition metals, but they are normally shown underneath the main table to save on space.

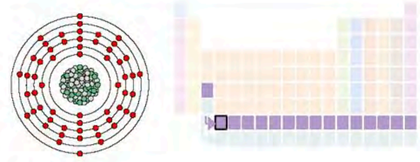
Atomic structure
Atoms of every element in this group have two outer electrons. The lanthanides have large atoms, all with six electron shells.

Physical properties
The lanthanides are dense, shiny metals, which tarnish easily when exposed to air. They do not conduct electricity very well.

Chemical properties
These elements react slowly with oxygen (O) at room temperature, but the reactions speed up when heated.

Compounds
Many lanthanides form compounds with oxygen called oxides. These are often used in lasers and magnets.

57
La
Lanthanum



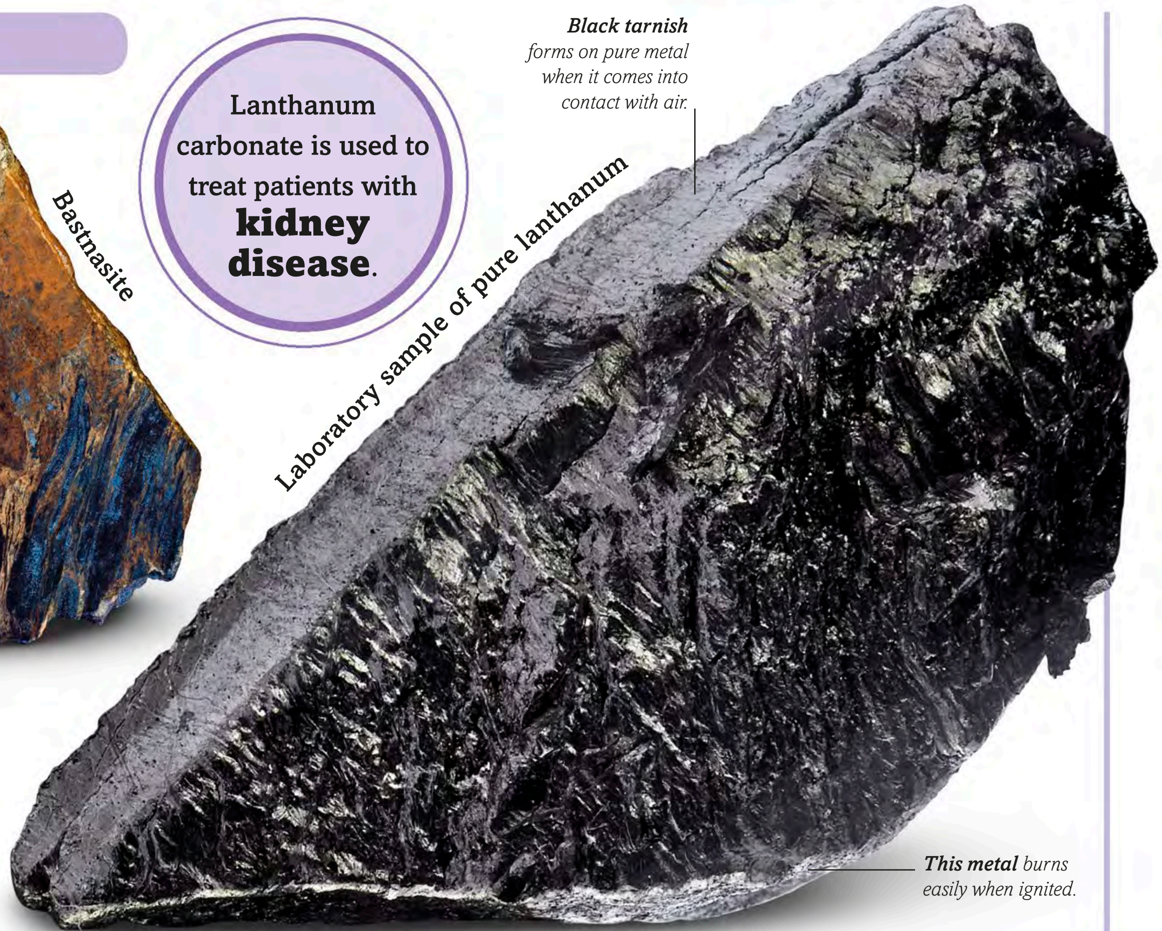
57 | 57 | 82
State: Solid
Discovery: 1839

Forms

Lanthanum carbonate is used to treat patients with **kidney disease**.

Bastnasite

This reddish-brown mineral *is also found in other colours, including white, tan, and grey.*



Laboratory sample of pure lanthanum

Black tarnish *forms on pure metal when it comes into contact with air.*

This metal *burns easily when ignited.*

Uses

Fluorescent lamp

This lamp *uses lanthanum to reduce the yellow colour in its light.*

Molten lanthanum

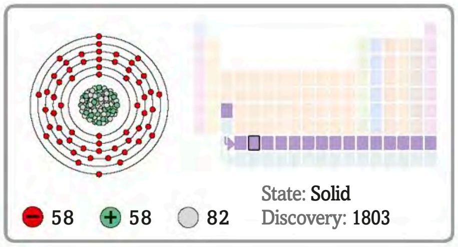
In its molten state*, lanthanum is used to smooth rough diamonds.*

Camera lens

This lens *can better focus light on an object due to the presence of lanthanum oxide in the glass.*

Although the word "lanthanum" means "to lie hidden", it is more abundant than most metals. For example, it is three times more common than lead. This element was discovered in the mineral cerite in 1839. However, it took chemists almost another 100 years to find a way to purify the metal. Today, the mineral **bastnasite** is a source of **pure lanthanum**. The element's applications range from its use in film studio lights and **lens-making** to refining petroleum.

58
Ce
Cerium



Cerium was the first of the lanthanides to be discovered. It is named after the dwarf planet Ceres, which was discovered two years before the element was isolated. Cerium is highly toxic when **pure**, but safer cerium compounds have some uses. The main use of cerium is in making phosphors, which are chemicals that produce lights of different colours. Phosphors are present in **flatscreen TVs** and bulbs.

Television

The inside of this screen *is coated with cerium-containing phosphors, which emit red, green, and blue light.*

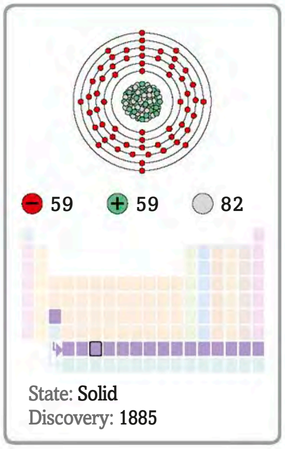
Laboratory sample of pure cerium

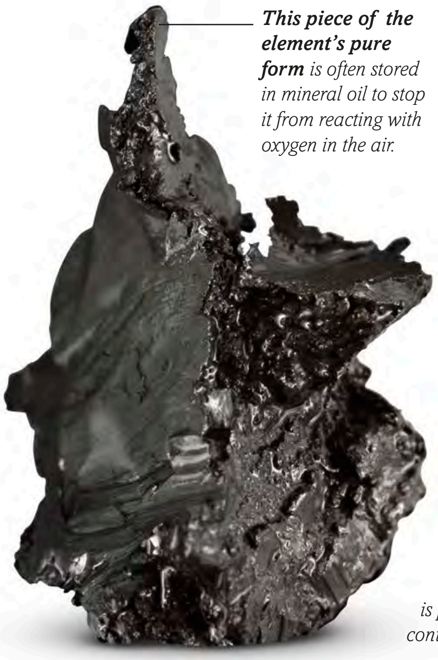
The pure form *of the metal tarnishes on contact with air.*

Kitchen spatula

This red colour *comes from a compound called cerium sulfide.*

59
Pr
Praseodymium





This piece of the element's pure form *is often stored in mineral oil to stop it from reacting with oxygen in the air.*

Laboratory sample of pure praseodymium

Part of this element's name comes from *prasinos*, the Greek word for "green". Normally a grey colour when pure, the element reacts slowly on contact with air to form a green coating. Praseodymium compounds give a yellow colour to glass and heat-resistant **ceramics**, and provide a green colour to some **artificial jewels**. This element also boosts the strength of magnets that contain it.

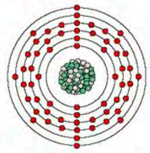
Yellow ceramic pot

This yellow colour *is produced by a solution containing praseodymium.*

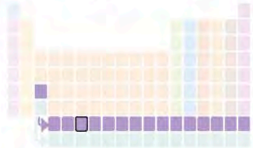
Green cubic zirconia

This artificial gem *gets its green colour from tiny amounts of a compound of praseodymium and oxygen.*

60 Nd Neodymium



60 60 84



State: Solid
Discovery: 1885

Pink glass

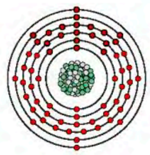
***This glass** gets its colour from very tiny amounts of neodymium.*

Strong magnets made of neodymium can be used to lift thousands of times their own mass. This element was discovered in 1885 by the Austrian chemist Carl Auer von Welsbach, and it was originally used to colour glass. Small amounts of neodymium turn **glass** pinkish purple. Today, this element is also employed in lasers used in eye surgery.

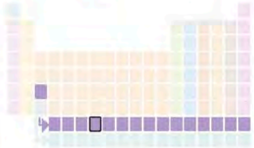
Laboratory sample of pure neodymium

***The pure element** turns black when it reacts with air.*

61 Pm Promethium



61 61 84

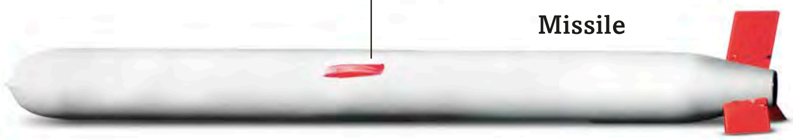


State: Solid
Discovery: 1945

***This paint** glows as a result of radioactive promethium.*

Promethium-rich paint in a tin seen from above

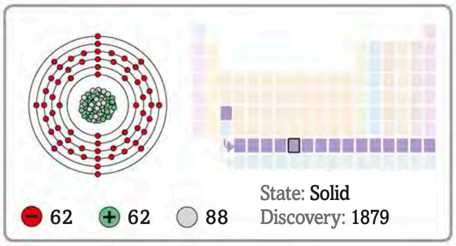
***This missile** uses radioactive promethium for electrical power.*



Missile

Promethium is the rarest lanthanide element. Any promethium that was in Earth's rocks decayed billions of years ago. Promethium is therefore produced artificially in nuclear reactors. Being very radioactive, it is used in some **missiles**, because it converts this radioactivity into electrical power. The addition of promethium also makes some **paints** glow in the dark.

62
Sm
Samarium



This element is named after the mineral samarskite from which it was first purified. However, another lanthanide-rich mineral called monazite is the main source of this element today. Samarium is mixed with cobalt to make permanent magnets that are often used in **electric guitars**.

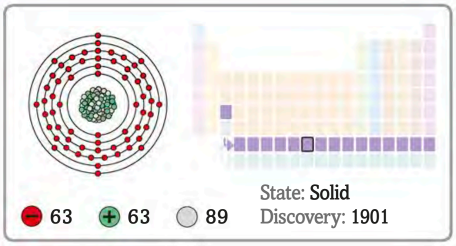

Guitar pickups

These pickups (components that sense vibrations produced by guitar strings) are made of samarium-cobalt magnets.


Laboratory sample of pure samarium

***This silvery white metal** darkens on contact with air.*

63
Eu
Europium



Europium was named after the continent of Europe. However, most of the world's supply of the element comes from the USA and China, where the mineral bastnasite is mined for the extraction of **pure europium**. A compound called europium oxide is used in euro and **British bank notes**. When placed under ultraviolet (UV) light, the compound gives off a red glow.

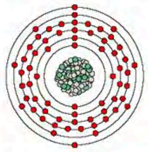
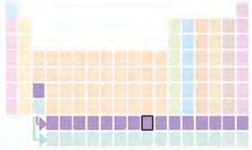

Laboratory sample of pure europium

***The crystals of this yellowish metal** often have patches of dark oxides.*

***This red glow** proves this note is real.*

Section of British note under UV light

64 Gd Gadolinium

64 64 93 State: Solid Discovery: 1880

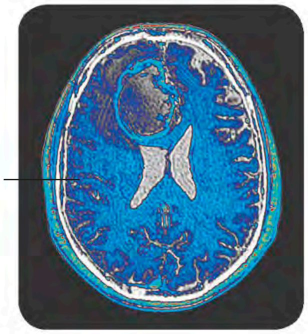
Gadolinium, and its mineral ore gadolinite, are named after the Finnish chemist Johan Gadolin, who discovered the element. Gadolinium compounds are used to obtain clear **MRI scans**. It is also used in electronics, and to make rust-resistant steel.

__This soft, silvery metal__ darkens when exposed to air.

Laboratory sample of pure gadolinium

__This mineral__ contains tiny amounts of gadolinium.

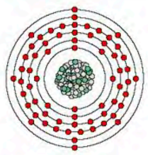
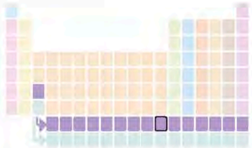
Gadolinite



__This image of the brain__ is clear because a gadolinium compound was injected into the patient's blood.

MRI scan of the human brain

65 Tb Terbium

65 65 94 State: Solid Discovery: 1843

Terbium is named after the village of Ytterby in Sweden. It is a silvery metal that can be obtained from the ore monazite. This element has only a few uses. **Pure terbium** is added to other metals to make powerful magnets used in sound-producing devices, such as the **SoundBug™**. Its compounds are used to line **mercury lamps**.

SoundBug™ device

__This device__ uses magnets to turn any flat surface, like a window, into a loudspeaker.

__The mercury vapour in this lamp__ produces ultraviolet light when electrified, and this is turned into a bright yellow glow by terbium.

Mercury lamp

__The pure metal__ is soft enough to be cut with a knife.

Laboratory sample of pure terbium

66 Dy Dysprosium

66 66 97

State: Solid
Discovery: 1886

Dysprosium reacts more easily with air and water than most other lanthanide metals. Although it was discovered in 1886, it took until the 1950s to purify it. This metal is often used with neodymium to produce magnets that are used in **car batteries**, wind turbines, and generators.

Fergusonite

This mineral *contains tiny amounts of dysprosium.*

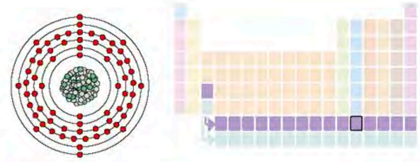
This pure metal *remains shiny at room temperature.*

Laboratory sample of pure dysprosium

Some hybrid car batteries *contain dysprosium.*

Hybrid car battery

67 Ho Holmium



67 67 98

State: Solid
Discovery: 1878

The Swedish chemist Per Teodor Cleve named holmium after the Swedish city of Stockholm. **Pure holmium** can produce a strong magnetic field and is therefore used in magnets. Its compounds are used to make lasers, and to colour glass and artificial jewels, such as **cubic zirconia**.

This artificial gemstone *is coloured red by small amounts of holmium.*

Bright, silver shine

Laboratory sample of pure holmium

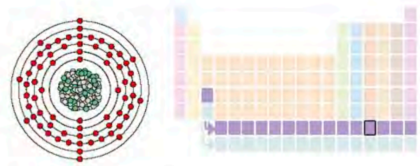
Red zirconia gemstone

Lanthanides

68

Er

Erbium



68 68 99

State: Solid
Discovery: 1843

This silvery element *slowly tarnishes on contact with air.*

Laboratory sample of pure erbium

This glass *contains erbium, which protects a welder's eyes from heat and bright light.*

Welding goggles

The rose pink finish *of this vase is from an erbium chloride glaze.*

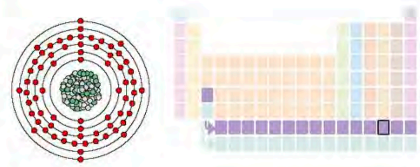
Pink pottery

Like terbium and ytterbium, erbium is also named after the Swedish village of Ytterby, near which it was discovered. This element does not occur in its **pure form** in nature, but it can be obtained from the mineral monazite. Many erbium compounds are pink in colour and are used to colour **pottery** and glass.

69

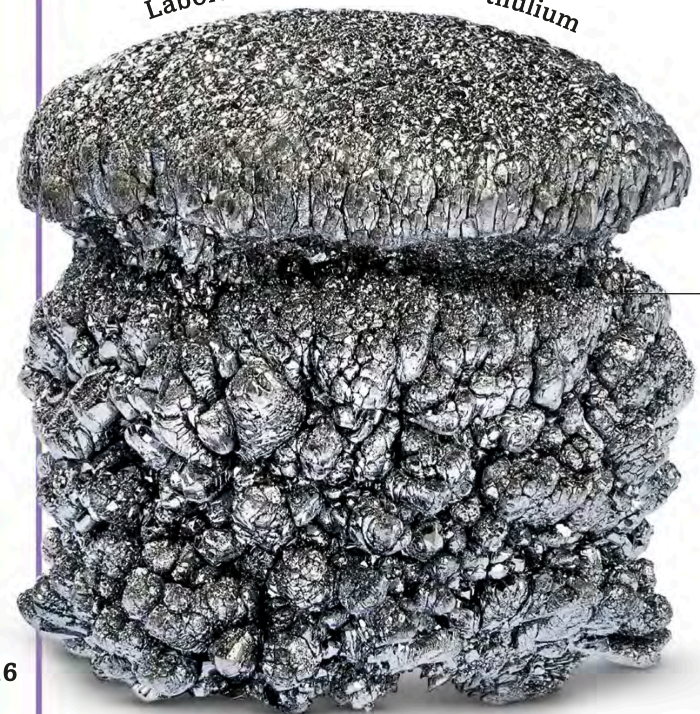
Tm

Thulium



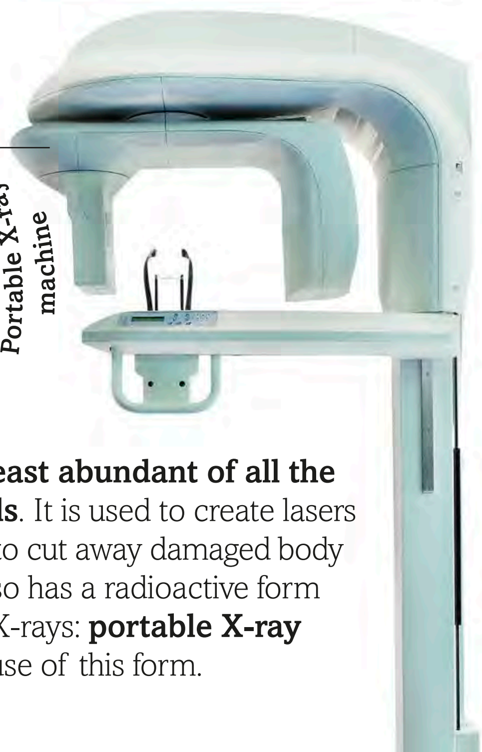
69 69 100

State: Solid
Discovery: 1879



Laboratory sample of pure thulium

This soft metal *glows blue under ultraviolet (UV) light.*

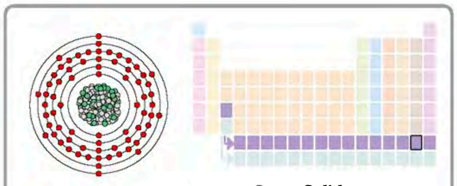


This machine *emits X-rays using a very small amount of thulium.*

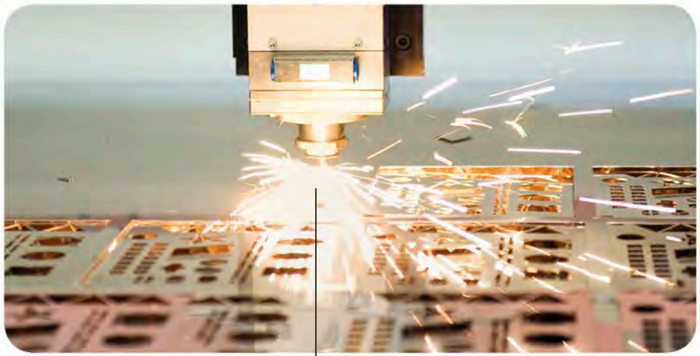
Portable X-ray machine

Thulium is the least abundant of all the lanthanide metals. It is used to create lasers that surgeons use to cut away damaged body tissue. Thulium also has a radioactive form that can produce X-rays: **portable X-ray machines** make use of this form.

70 Yb Ytterbium



Ytterbium tends to be more reactive than other lanthanide metals. It is stored in sealed containers to stop the metal from reacting with oxygen. The **pure metal** has only a few uses. A small amount of ytterbium is used in making steel, while its compounds are used in some **lasers**.



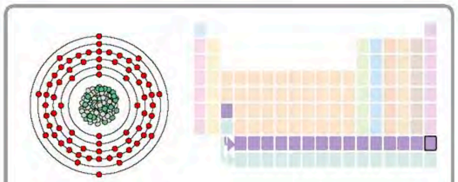
Laser cutting

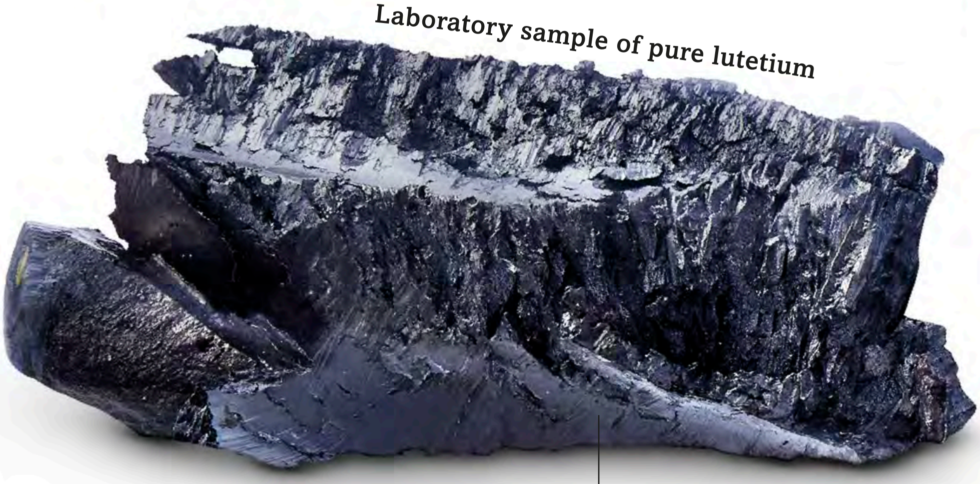
An ytterbium laser *can cut through metals and plastics.*

Laboratory sample of pure ytterbium

This bright, shiny metal *can be hammered into thin sheets.*

71 Lu Lutetium





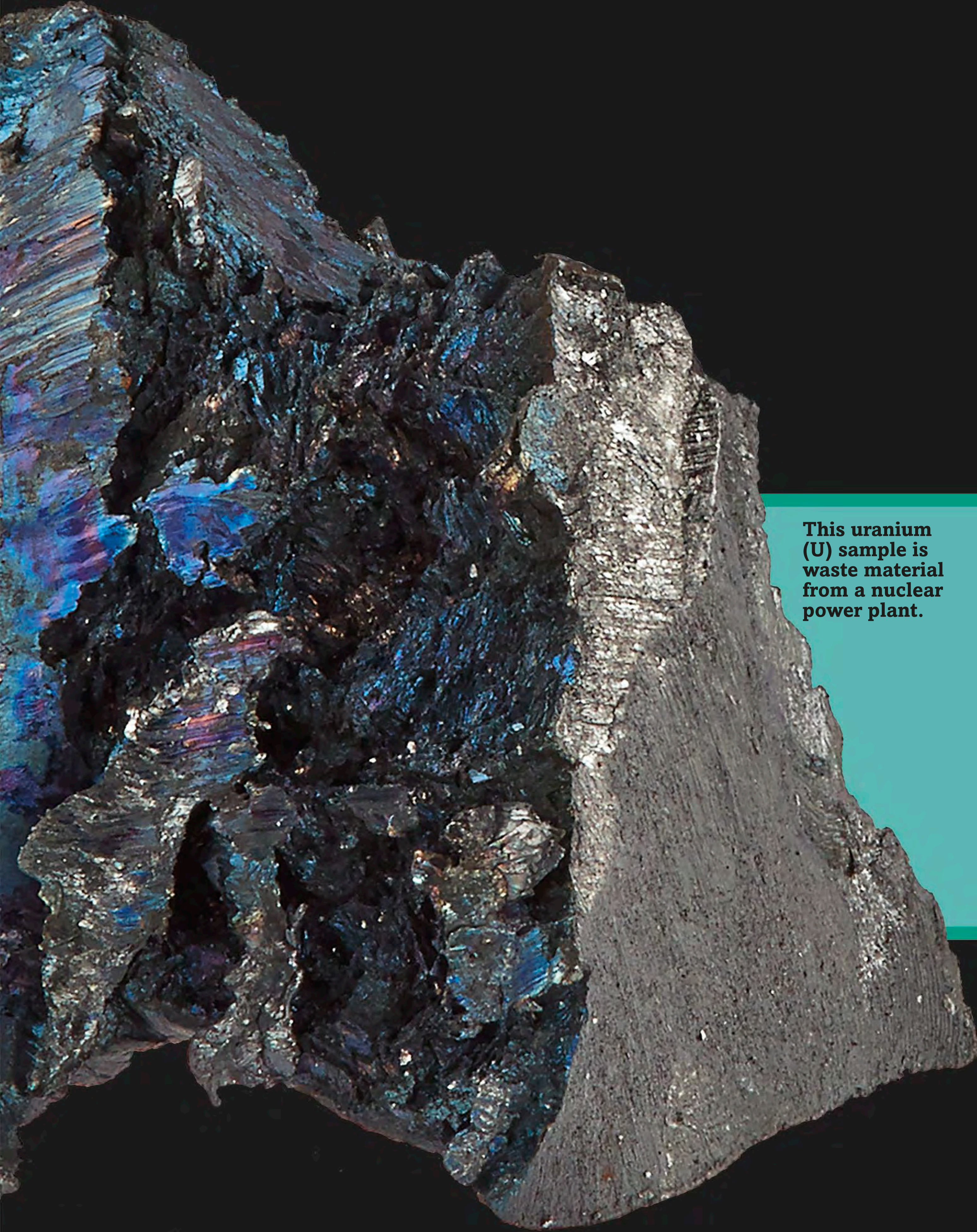
Laboratory sample of pure lutetium

This element *is the hardest and densest lanthanide metal.*

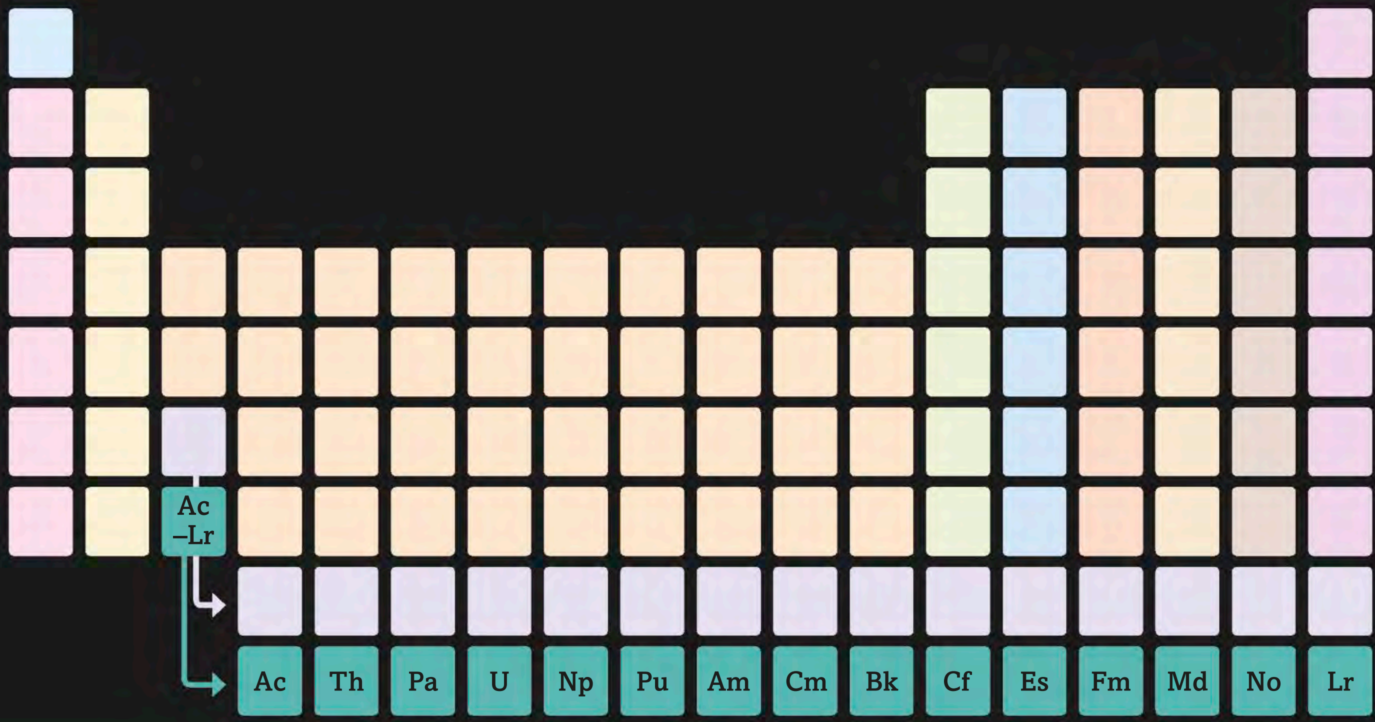
Oil refinery

Some oil refineries *use lutetium to break down crude oil to make fuels, such as petrol and diesel.*

Lutetium was the last of the rare earth metals to be discovered. It is also the final member of the lanthanides. In its **pure form**, lutetium is very reactive and catches fire easily. It is rare and has few uses, mainly as a substance mixed with crude **oil**.



This uranium (U) sample is waste material from a nuclear power plant.



Actinides

These metals are named after actinium (Ac), the first member of the group. Although this group is often shown as the bottom row in the periodic table, to save space, they actually sit between radium (Ra), an alkali earth metal, and Rutherfodium (Rf), a transition metal. All the elements in this group are radioactive, and the final nine members are artificially produced in laboratories.

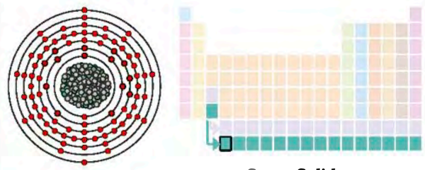
Atomic structure
All the elements in this group have two electrons in their outer shell. Their atoms all have seven electron shells.

Physical properties
Natural actinides are dense metals with high melting points. The physical properties of most of the artificial ones are unknown.

Chemical properties
The actinides are reactive metals and are never found in pure form in nature. They react easily with air, the halogens, and sulfur (S).

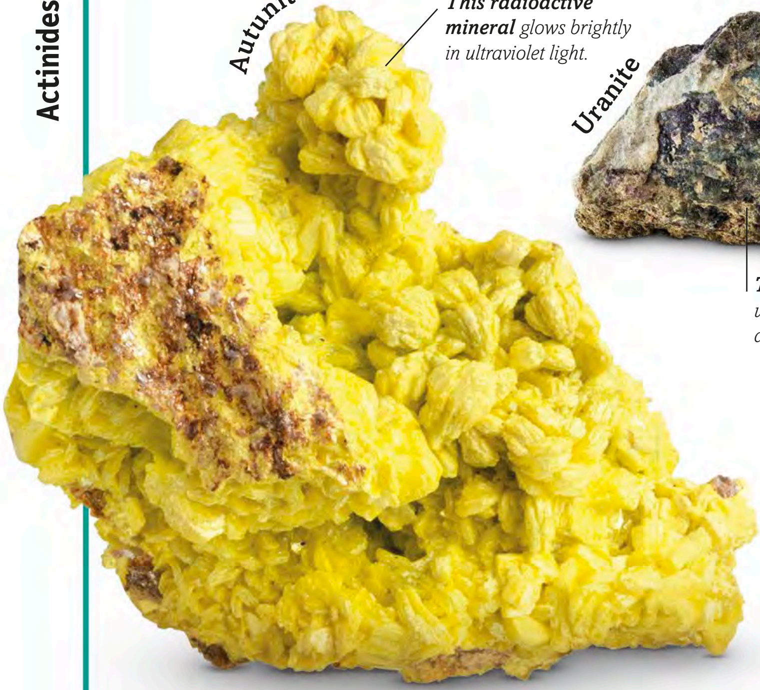
Compounds
Actinides form colourful compounds with halogens. Most actinide ores also contain compounds of oxygen (0) called oxides.

89 Ac Actinium



State: Solid
Discovery: 1899
89 89 138

Autunite



This radioactive mineral *glows brightly in ultraviolet light.*

Uranite

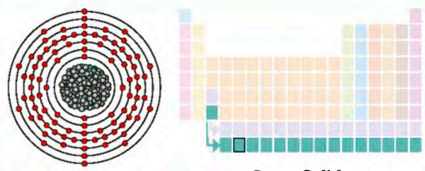
This ore *contains uranium, which breaks down into actinium.*

This device *uses radioactive actinium to measure the amount of water.*

Neutron probe

Rare in nature, actinium is a metal formed by the decay of other radioactive elements. Its atoms are unstable and break down to make the elements francium and radon. Actinium is found in tiny amounts in uranium ores, such as **uranite**, and has limited applications. Its isotopes are used in radiation therapy to treat cancer.

90 Th Thorium



State: Solid
Discovery: 1829
90 90 142

Monazite

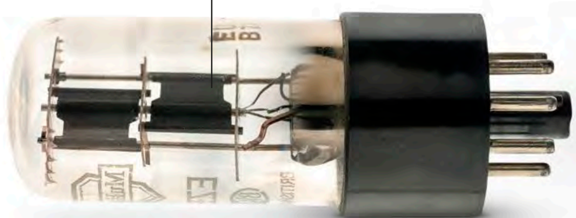
The most common natural radioactive metal, thorium is used inside vacuum tubes to allow an electric current to flow. It can also undergo nuclear fission, a process in which atoms split in two and release energy. Scientists are exploring ways of making thorium-powered nuclear reactors that produce electricity.

This durable rock *made of solidified lava contains 12% thorium.*

This thorium coating *creates an electric current by releasing electrons.*

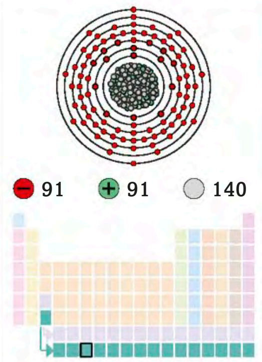
Thorianite

This ore *contains small crystals of thorium compounds.*



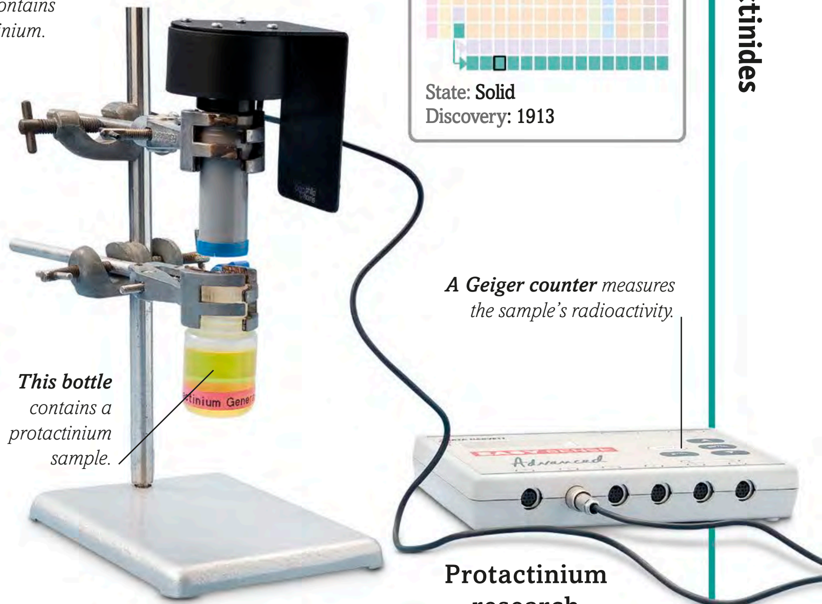
Vacuum tube

91 Pa Protactinium



State: Solid
Discovery: 1913

Torbernite

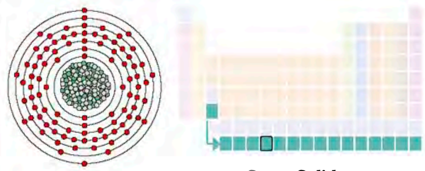


Protactinium research

The name protactinium means "before actinium". This is because a uranium atom decays to form a protactinium atom, which then quickly breaks down into an actinium atom. Small quantities of protactinium are found in ancient sands and mud. Geologists use Geiger counters to carry out **research** to calculate how old the sands are.

Nuclear waste

92
U
Uranium



92 92 146
State: Solid
Discovery: 1789

Named after the planet Uranus, uranium was the first known radioactive element. In the early 20th century, some manufacturers used uranium in **glass bowl** glazes, only to realize later that it was a harmful metal. An unstable form, called uranium-235, is used as fuel in nuclear reactors and in atomic bombs.

Chunk of pure uranium

This sample of ***pure uranium*** *is waste from a nuclear plant.*

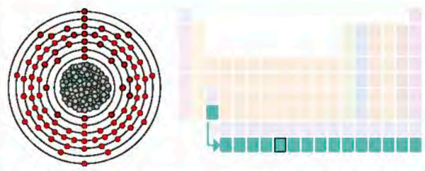
These black sections *contain uranium dioxide, which is the main source of uranium.*

Uraninite

Uranium mixed into glass *makes this bowl glow bright green under ultraviolet (UV) lamps.*

Glass bowl

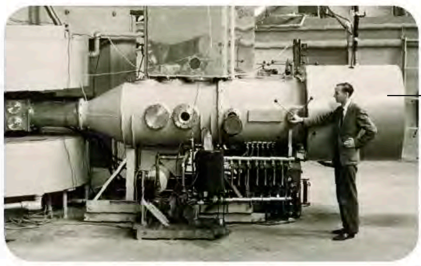
93
Np
Neptunium



93 93 144
State: Solid
Discovery: 1940

The radioactive elements *in this mineral decay to form neptunium.*

Uraninite

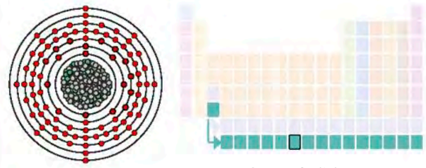


This cyclotron*, built in 1938, was used to discover neptunium.*

Cyclotron at the University of California, Berkeley, USA

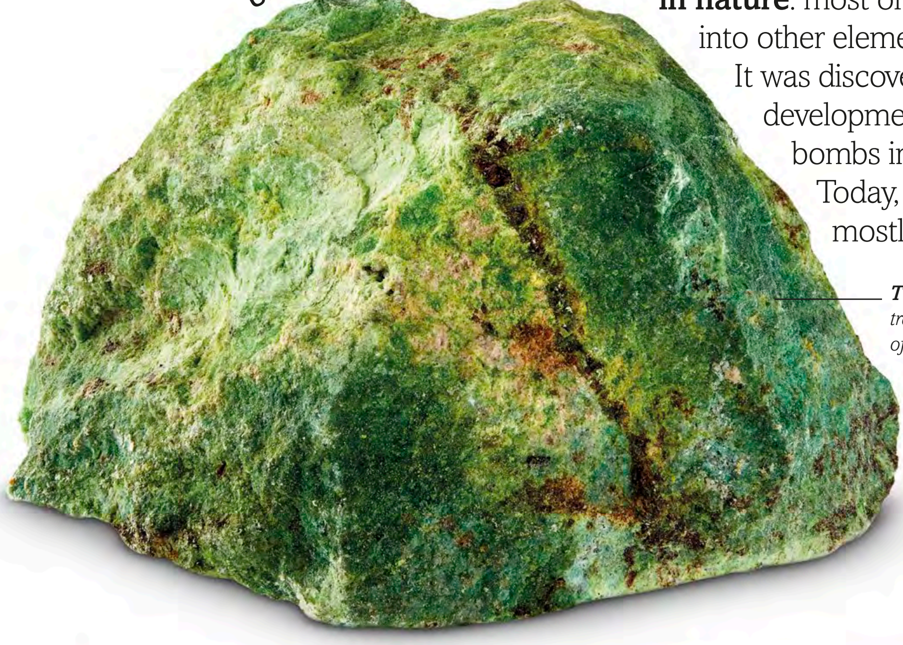
Sitting next to uranium in the periodic table, neptunium was named after the planet Neptune. It exists in small amounts in radioactive ores, such as aeschynite. It forms during nuclear explosions and was first identified inside a machine called a **cyclotron**. There are no known uses for neptunium.

94 Pu Plutonium



State: Solid
Discovery: 1940
94 | 94 | 239

Uraninite



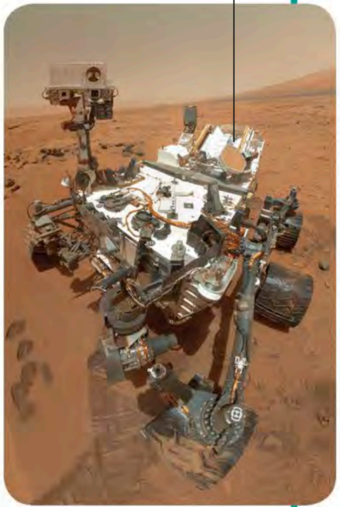
Hardly any plutonium exists in nature: most of it has decayed into other elements over time. It was discovered during the development of nuclear bombs in World War II. Today, plutonium is used mostly as a nuclear fuel.

***This ore** contains trace amounts of plutonium.*

***This plutonium battery** was used in early pacemakers.*

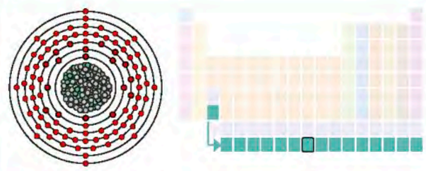
1970's pacemaker battery

***This Martian rover** uses the heat given off by a supply of plutonium to generate electrical power.*



Curiosity Rover

95 Am Americium



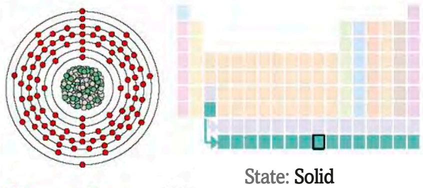
State: Solid
Discovery: 1944
95 | 95 | 148

Smoke detector component

This metallic element is not found in nature. Instead, it is produced inside nuclear reactors when uranium or plutonium atoms are bombarded with neutrons. Remarkably, americium is the most common radioactive element used in the home. Radioactivity emitted by americium atoms causes the air inside **smoke detectors** to conduct electricity. When smoke disrupts the electric current, an alarm goes off.

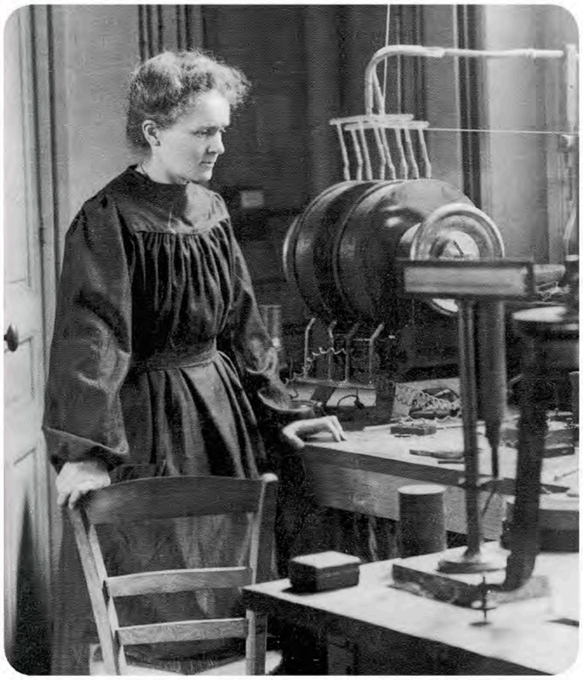
***This smoke detector** contains tiny, harmless quantities of americium.*

96 Cm Curium



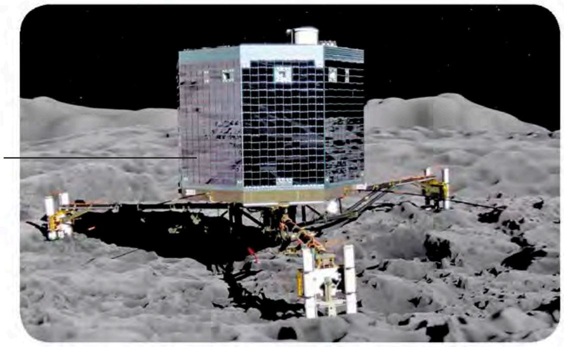
96 96 151

State: Solid
Discovery: 1944



Marie Curie working in her laboratory

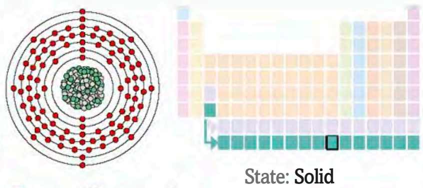
This lander studied the surface composition of the comet 67P.



Philae lander

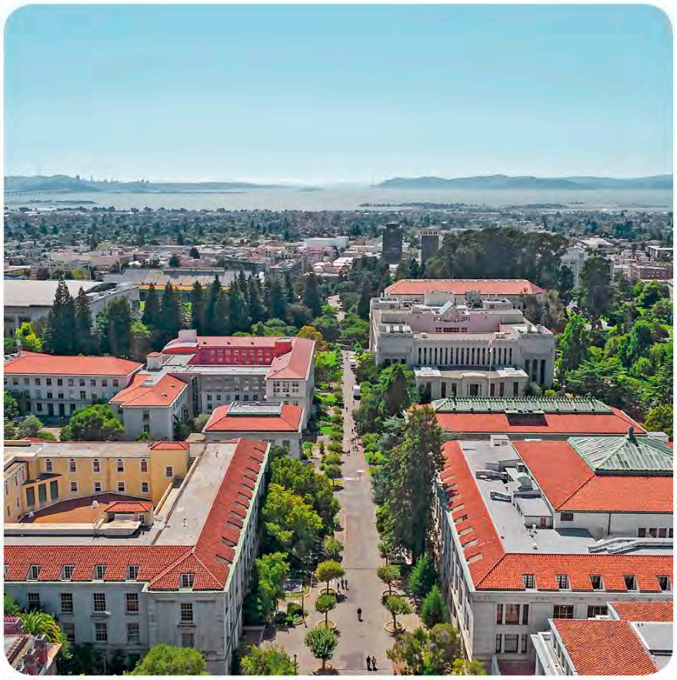
Curium is a silvery, radioactive metal that glows reddish purple in the dark. This element was discovered by the US scientist Glenn T Seaborg at the University of California. It was named after **Marie Curie**, the scientist who discovered the element polonium. Several space probes, such as the **Philae comet lander**, use X-ray devices containing curium to study their environment.

97 Bk Berkelium



97 97 150

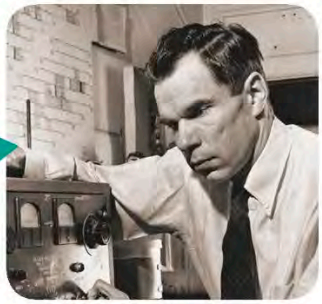
State: Solid
Discovery: 1949



University of California, Berkeley campus, USA

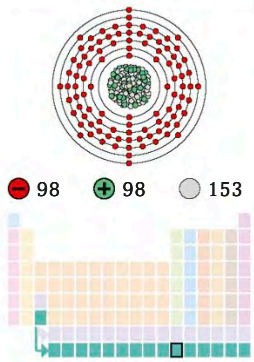
This element was named after the city of Berkeley – home to the University of California – where this artificial element was discovered. It was first synthesized by **Glenn T Seaborg**. Berkelium has no uses other than the creation of heavier elements, such as tennessine.

Seaborg helped develop the atom bomb, but **opposed using it** in World War II.



Glenn T Seaborg

98
Cf
Californium



State: Solid
Discovery: 1950

Water detector

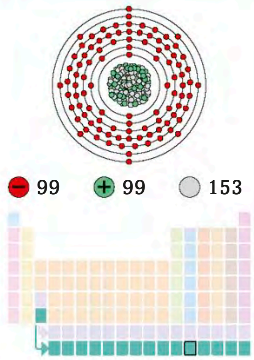
This machine uses californium to find water underground.

Pellets of radioactive californium

This isotope, or form, of californium produces a lot of neutrons.

Californium is named after the US state of California. This soft, silvery metal does not exist in nature and is made by smashing berkelium atoms with neutrons in a particle accelerator (a machine in which atoms are smashed together). This **radioactive element** is used in the treatment of cancer.

99
Es
Einsteinium



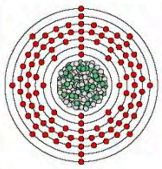
State: Solid
Discovery: 1952

Albert Einstein in his study

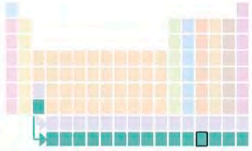
Only a **few milligrams** of einsteinium are made **every year**.

Einsteinium was discovered in the chemicals left over after the first hydrogen bomb test in 1952. The huge explosion fused smaller atoms together to make larger ones, including einsteinium. This element was named after the great German-born scientist **Albert Einstein**, and was found to be a silvery, radioactive metal that glows blue in the dark. It is only used for making heavier elements, such as mendelevium.

100 Fm Fermium



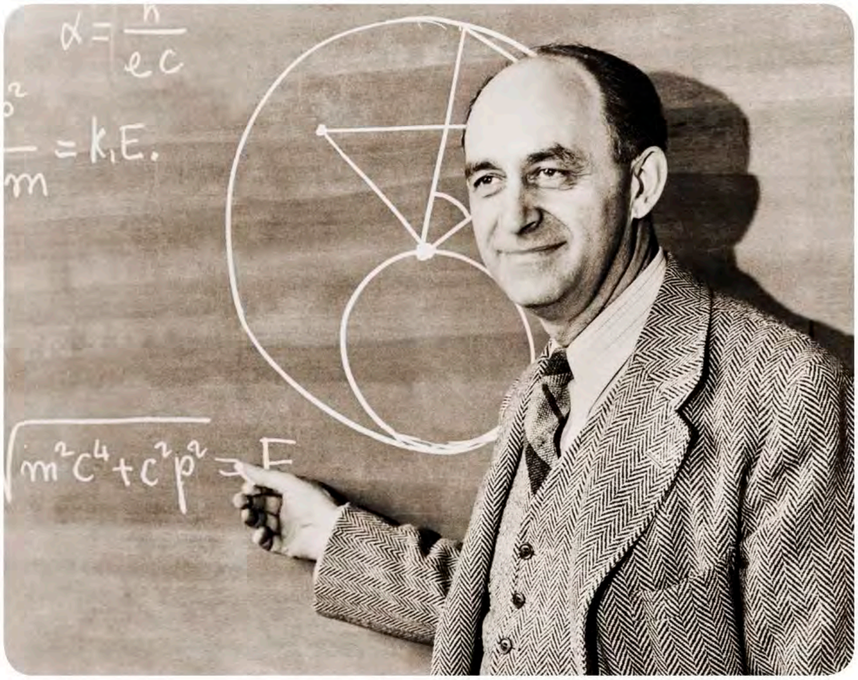
100 100 157



State: Solid
Discovery: 1953

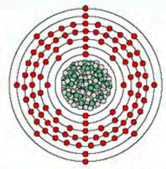
This artificial element was named after the Italian scientist Enrico Fermi. He built the first nuclear reactor in 1942, starting the American effort to build nuclear weapons during World War II. Fermium was first identified in the debris of an atom bomb test in 1953. This unstable element has no known uses beyond research.

Some scientists call Enrico Fermi the "father of the **atomic age**".

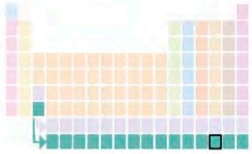


Enrico Fermi

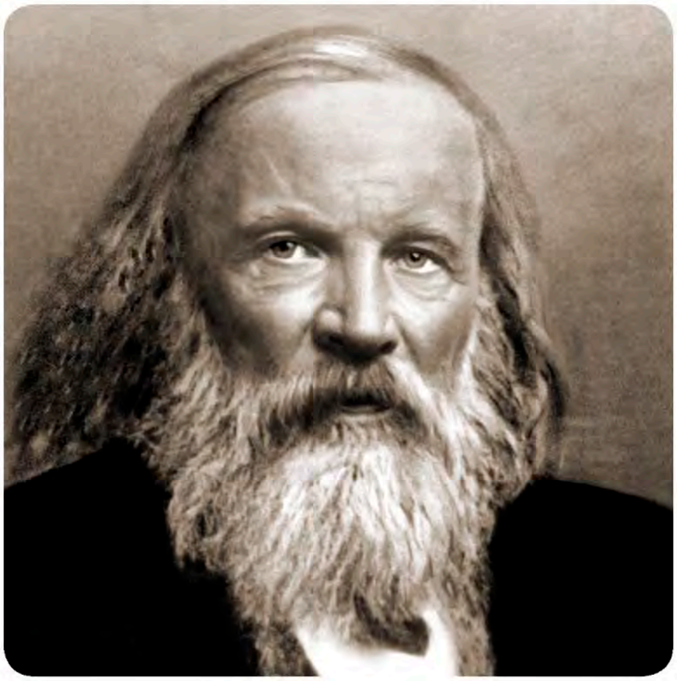
101 Md Mendelevium



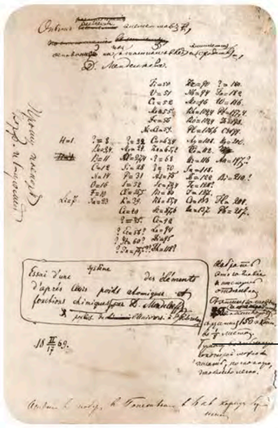
101 101 157



State: Solid
Discovery: 1955



Dmitri Mendeleev

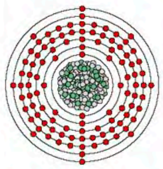


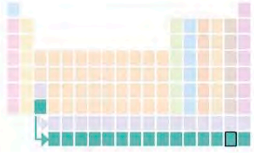
Mendeleev's periodic table

Mendeleev's notes *from 1869 show his method of arranging elements in columns and rows.*

Mendelevium is named after the Russian chemist Dmitri Mendeleev, who invented the periodic table. Mendelevium is produced in very small amounts by firing parts of helium atoms at einsteinium atoms in a particle accelerator (a machine in which atoms are smashed together).

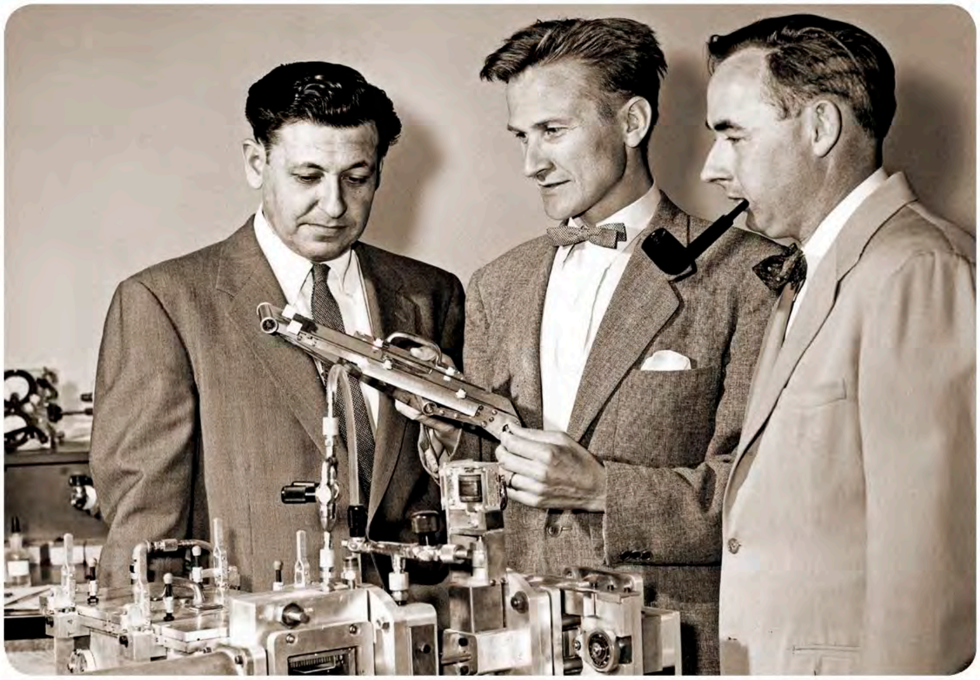
102 No Nobelium





102 102 157

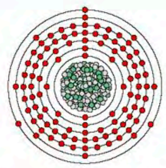
State: Solid
Discovery: 1963



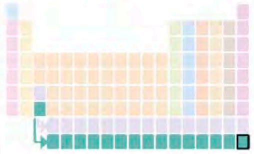
Albert Ghiorso, Torbjørn Sikkeland, and John R Walton

This artificial metal is named after the Swedish chemist Alfred Nobel, who started the Nobel Prize. It was discovered in 1963 by a team of scientists working in California, USA. This team included **Albert Ghiorso**, **Torbjørn Sikkeland**, and **John R Walton**. They used a particle accelerator to fire carbon atoms at curium atoms, creating nobelium atoms, which broke apart within minutes.

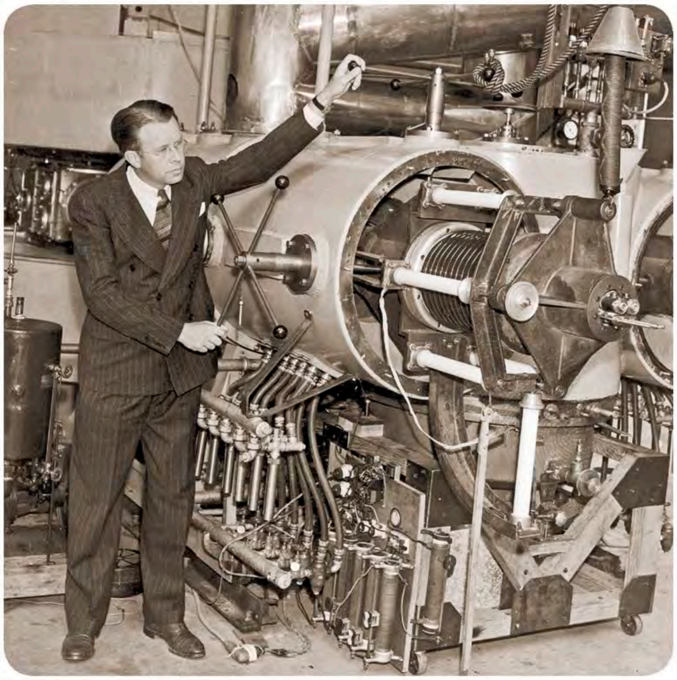
103 Lr Lawrencium



103 103 163



State: Solid
Discovery: 1965

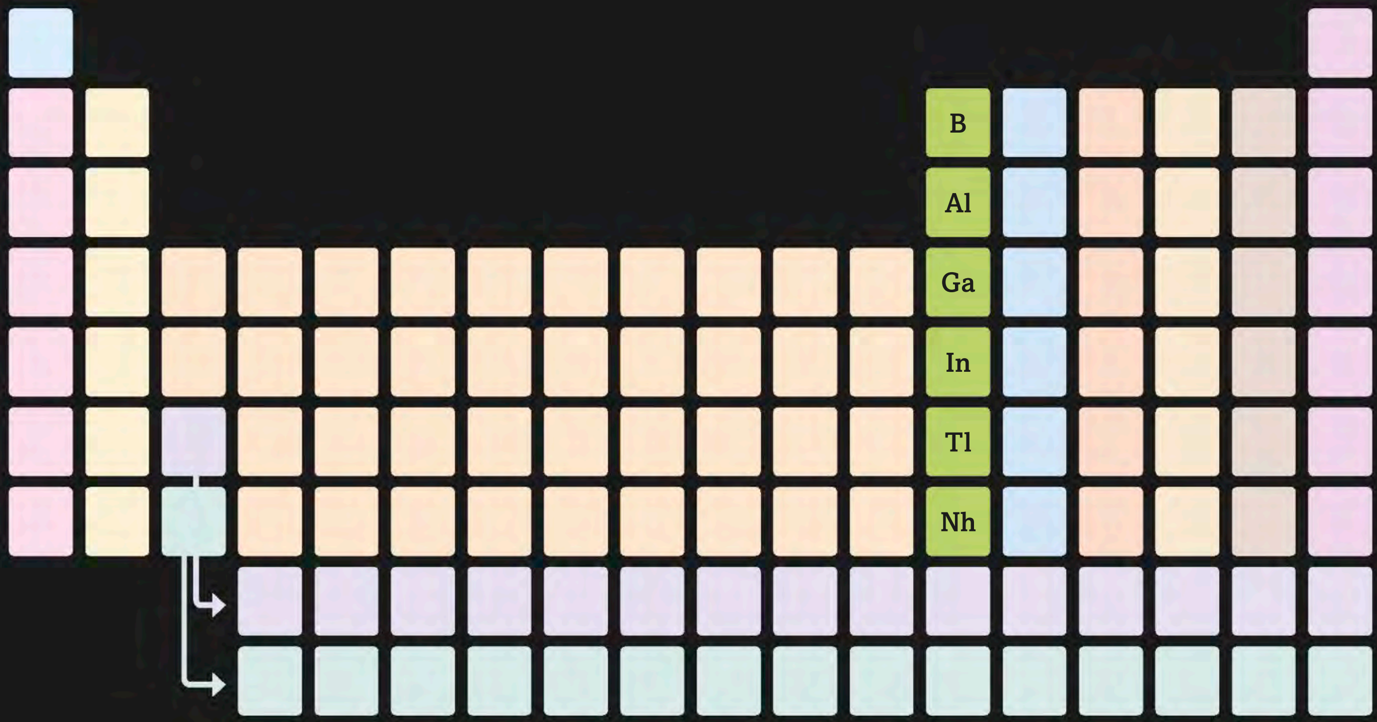


An early cyclotron

Lawrencium was produced at the **Berkeley lab** set up by Ernest Lawrence.

Lawrencium is named after the US scientist Ernest Lawrence, who developed the first cyclotron particle accelerator. This is a machine in which parts of atoms are smashed together by making them spin round in circles. Lawrencium atoms were produced in a similar machine by firing boron atoms at californium atoms.

Pure gallium (Ga) becomes liquid at 29°C (84.2°F).



The Boron Group

This group contains five natural elements and one artificial element called nihonium (Nh). Although these elements are not very reactive, none of them are found in a pure form in nature. Boron (B), the first member, is a semi-metal (an element that has properties of both metals and non-metals), while the rest are metals. The second member, aluminium (Al), is the most common metal in Earth's rocks.

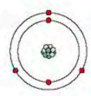
Atomic structure
Members of this group have three electrons in the outer shell of every atom. Some elements have unstable isotopes.

Physical properties
All elements, except boron, are shiny solids. Every member of this group is soft, except for boron (B), which is one of the hardest elements.

Chemical properties
Most of the elements don't react with water. Aluminium (Al) forms an oxide layer in water, and can react with it when this layer is corroded.

Compounds
They form compounds by losing electrons to other elements. All of them react with oxygen (O) by bonding to three oxygen atoms.

5 B Boron




5 5 6

State: Solid
Discovery: 1808

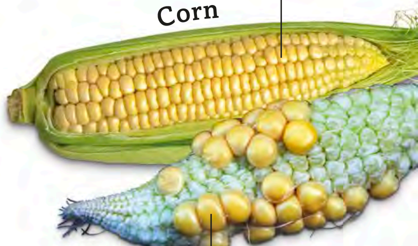
Forms

Ulexite

This translucent mineral *is found in dried lakes.*

Laboratory sample of pure boron

This metal *is dark and slightly shiny.*



Corn

Boron-rich corn

Boron-deficient corn *does not grow properly.*

Kernite

This is a colourless form *of a compound of sodium and boron.*

Colemanite

Some boron compounds are among the toughest artificial substances on Earth, with only diamond being harder. This element is a very hard material and becomes even harder when made to react with carbon or nitrogen. **Pure boron** can be extracted from various minerals, including **ulexite** and **kernite**. The demand for this element was once so high that people moved to live in the extreme heat of **Death Valley, USA**, to work in boron mines there. Compounds of boron in soil are essential for plants to grow healthily. We use boron in our homes every day.

This searing desert is one of the main places on Earth where boron is found.

Death Valley, USA

Needle- and leaf-shaped crystals

Uses

Measuring cup

This tough glass contains boron oxide.

Boric acid

These white crystals are obtained from sodium borate.

LCD screen

This screen is composed of boron-rich glass, which makes it scratch-resistant.

This clay is bouncy but also firm because it contains boron.

Modelling clay

Boron carbide is one of the **hardest** materials in use today.

The protective body of this tank contains boron carbide, a compound of boron and carbon.

Military tank

THÉNARD AND GAY-LUSSAC

The salt sodium borate, also called borax, was already in use 1,000 years ago. In 1808, the Frenchmen Joseph Louis Gay-Lussac and Louis Jacques Thénard isolated pure boron by heating borax with potassium.

Louis Jacques Thénard
Born into a poor family, Thénard excelled as a scientist. He also discovered a compound called hydrogen peroxide.

Joseph Louis Gay-Lussac
This French chemist is also remembered for discovering that the pressure of a gas goes up with its temperature.

Tough, heat-resistant glassware, such as **measuring cups**, are strengthened with boron. **Boric acid** is a natural antiseptic and can be used to treat minor cuts and scrapes. A flexible layer of boron-based glass fibres is used to toughen thin **LCD screens** for televisions and laptops. Even some kinds of **modelling clay** and bouncy silly putty contain boron compounds. Boron is named after a crumbly white salt called borax, which is used in detergents. The element is also present in a diverse range of objects, from insecticides to armour for **military tanks**.

13
Al

Aluminium

13 13 14

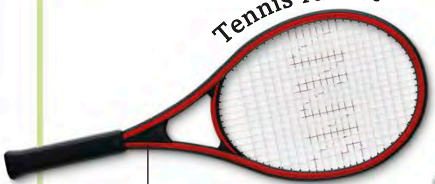
State: Solid
Discovery: 1825

Forms

Although aluminium is the most common metal in Earth's rocks, scientists did not discover it until the early 1800s. Even then, it took a further 80 years for scientists to work out how to use the ore **bauxite** to extract large amounts of **pure aluminium**. It can also be found in other minerals, including **variscite**. Today, aluminium is often recycled because producing it anew requires 15 times more energy. The metal makes a strong, shiny **foil** when rolled flat, and is useful for storing foods. A **fire protection suit** made from

Uses

Tennis racket



This aluminium frame makes the racket light.

This foil does not break even as it is bent and twisted.

Aluminium foil

This suit protects against temperatures up to 1,000°C (1,800°F).

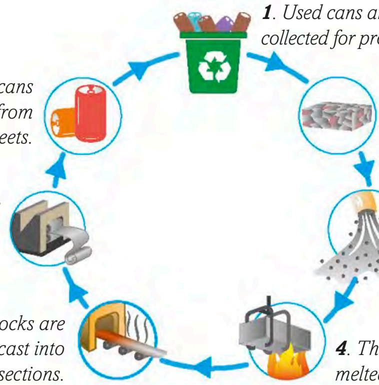
Fire protection suit

Aluminium can

This can is produced from recycled aluminium.

RECYCLING ALUMINIUM

Aluminium is expensive to purify, so it is often recycled instead. Drinks cans are almost 100 per cent pure aluminium and can be shredded, melted down, and made into new cans.



1. Used cans are collected for processing.

2. They are crushed into small bricks.

3. The blocks are shredded into tiny pieces.

4. The pieces are then melted into large blocks.

5. The blocks are then cast into smaller sections.

6. These are pressed into metal sheets.

7. New cans are made from these sheets.

Recycling one aluminium can saves enough energy to run a TV for three hours.

Smartwatch

The aluminium casing protects the touchscreen.

Parts of this dome are made of aluminium.

Esplanade Theatre, Singapore

Aluminium cables are lightweight.

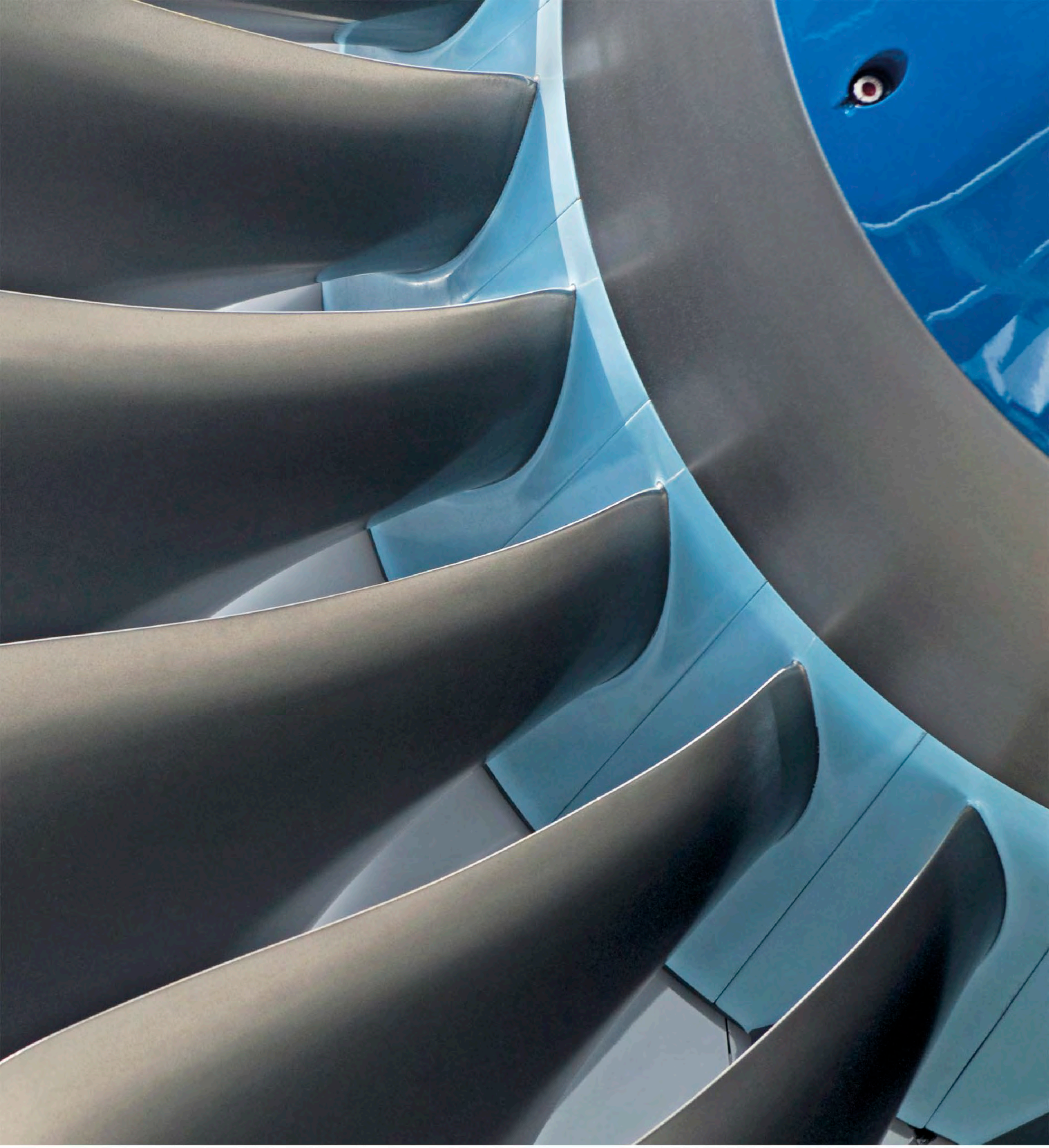
Overhead cables

Boeing 737

This plane's fuselage is built from sheets of aluminium stretched around a frame.

this foil reflects away heat. Aluminium is the most widely used metal after iron. It is very lightweight compared to iron's alloy steel and almost as strong. A dome made from aluminium, such as the one in the **Esplanade Theatre** in Singapore, can be much larger than a steel-based one, which would collapse under its own weight. Aluminium is also a good electrical conductor and so is used in **overhead cables**. Tough aluminium alloys are used to produce parts of some aircraft, including the **Boeing 737**.

JET TURBINE The curved blades of this jet engine are shaped very precisely to catch the air, and they are also strong enough to stay stiff when working at high temperatures. There are several tough metals that fit these requirements, but most are very dense, making them too heavy for an engine powering an aeroplane into the air. That leaves only one metal for the job: aluminium.



Aluminium is what makes high-speed, long-range air travel possible. Easily moulded, it is one-quarter the weight of steel, and it never rusts. Steel is stronger, but a plane made from it would be too heavy to fly. Instead aluminium is mixed with titanium and steel to produce tough yet lightweight alloys, which are used in the engines and bodies of jet aircraft. There is almost twice as much aluminium in Earth's rock as there is iron. However, purifying aluminium takes a lot of energy. Once pure, though, it can be recycled over and over again. So, one day these engine blades might transform into a fizzy drink can.

31
Ga
Gallium

State: Solid
Discovery: 1875

31 31 39

Forms

Diaspore

The needle-like crystals *form on the surface.*

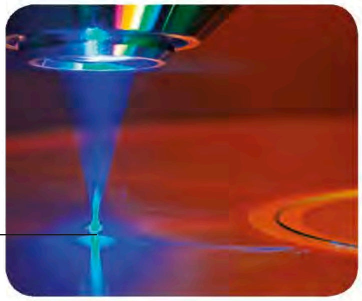
Cube of melting gallium

Pure gallium *has a very low melting point.*

Uses

Thermometer

This medical thermometer *uses a gallium alloy instead of mercury.*

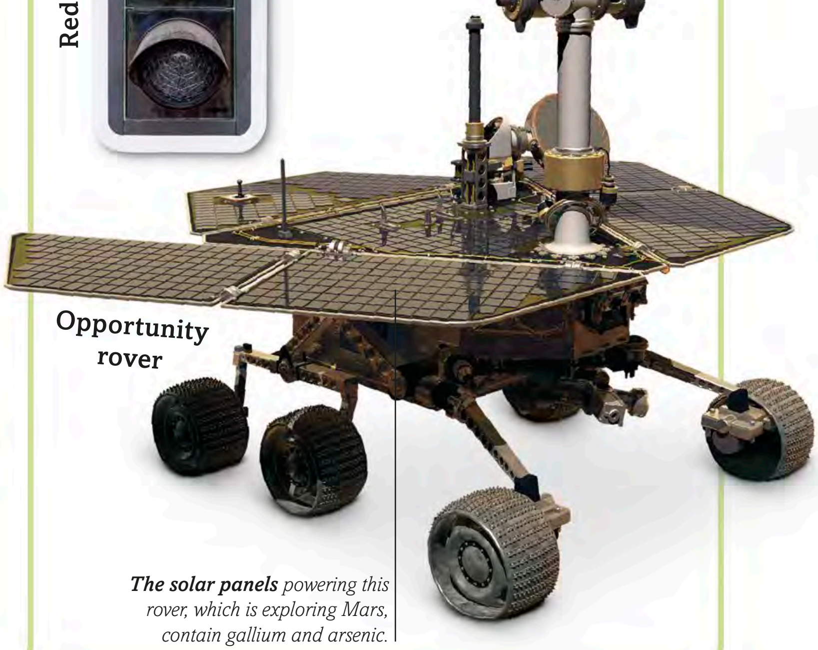


Blu-ray disc

A gallium laser *is used to read Blu-ray discs.*

Red LED lights

The red LED *gets its colour from gallium compounds.*



Opportunity rover

The solar panels *powering this rover, which is exploring Mars, contain gallium and arsenic.*

Gallium melts at just 29°C (84.2°F), which means it soon becomes liquid when held in the hand. This element is found in small amounts in ores of zinc and aluminium, such as **diaspore**. **Pure gallium** is isolated when the other elements from this ore are extracted.

Gallium has a number of uses. It is mixed with indium and tin to form a liquid alloy called galinstan, which can be used in **thermometers**. Gallium is also found in **Blu-ray lasers**, **LEDs**, and some solar panels, such as those on NASA's Mars **rovers**.

49
In
Indium

49 49 66

State: Solid
Discovery: 1863

Forms

When bent, indium produces a **"tin cry"** – a sound similar to a **scream**.

Sphalerite

This zinc mineral *is the main source of indium.*

Pure indium mould cast in a laboratory

Pure indium *is soft enough to draw lines on paper.*

Uses

This touchscreen *has a grid of very thin, transparent wires made of indium tin oxide.*

Touchscreen tablet

Welder's goggles

Protective goggles *coated with indium stop the heat damaging the welder's eyes.*

Transistor

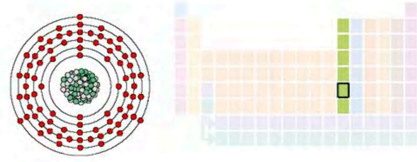
The tiny electronic switches *inside this transistor contain indium.*

This glass coated with indium oxide *is shiny but still lets light through.*

Windows in a building

Indium is named after indigo, which is the colour of the light its atoms release when electrified. Its minerals are rare, and most of the metal is obtained from lead and zinc ores, such as **sphalerite**. **Pure indium** is very soft, and the element is mostly used in compound form. For example, a compound called indium tin oxide used on a **touchscreen** allows the computer to detect when a finger makes contact with the screen. Indium is also required in microchips, and to produce **welder's goggles** and **windows** that are heat- and glare-proof.

81
Tl
Thallium

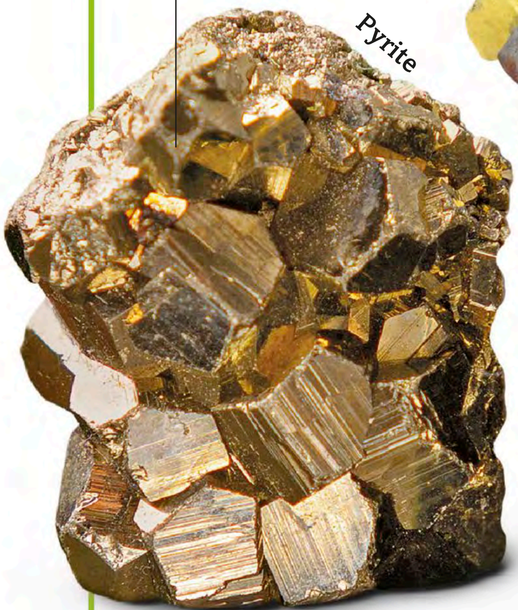


81 81 123
State: Solid
Discovery: 1861

Forms

Thallium alum

The grey crust *on this aluminium mineral contains small amounts of thallium.*



Pyrite

This mineral *contains iron, sulfur, and tiny amounts of thallium.*

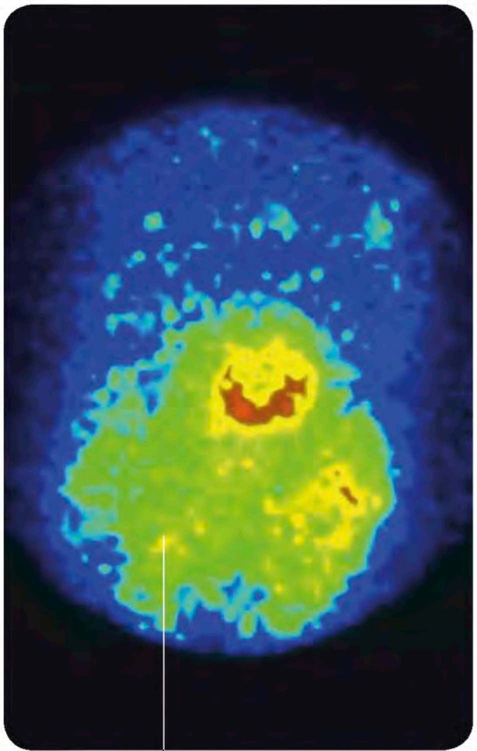
Laboratory sample of pure thallium in an airless vial

This soft and silvery metal *is kept in a sealed glass tube as it is highly toxic and reacts easily with air.*

Thallium was named after the Greek word *thallos*, which means "green shoot": it was first identified from the colours in its flame, which includes a bright green light. Thallium was discovered in 1861 by William Crookes and Claude-Auguste Lamy. Although both chemists worked separately, they found the element in the same way – as a residue while making strong acids using the mineral **pyrite**. Thallium was later found to exist in larger amounts in other minerals, including **thallium alum**. **Pure thallium** is toxic and has to be handled

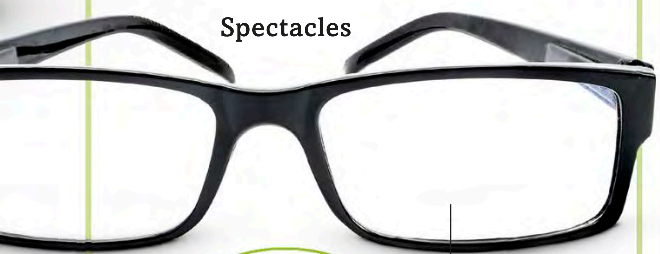
Uses

Heart function scan



Blood injected with a thallium compound *shows up on a patient's heart scan.*

Spectacles

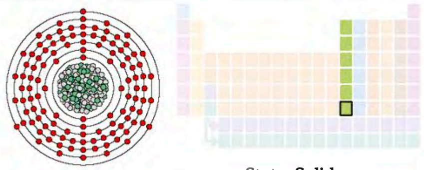


These thin lenses *contain strong, thallium-infused glass.*

Until the 1970s, thallium salts were commonly used as **ant poison**.

toxic and has to be handled with care when used. A chlorine compound of thallium is used in **scans** to study a patient's blood circulation. Thallium oxide also helps make glass stronger for use in **spectacles** and cameras.

113 Nh Nihonium



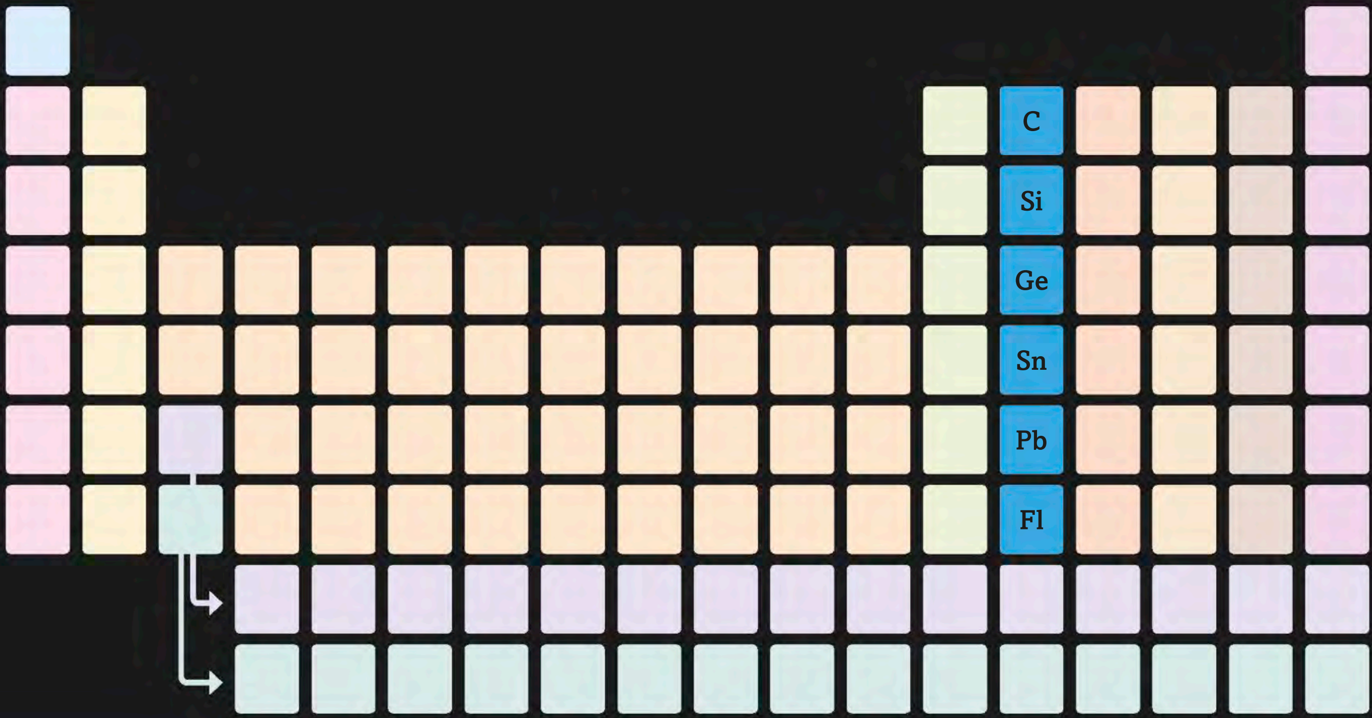
113 113 183

State: Solid
Discovery: 2004

Kozuka Morita (left), with a visiting official at the RIKEN Nuclear Research Centre, Wako, Japan

Nihonium was named after the Japanese word *nihon*, which means Japan. A metallic element, nihonium was first detected in 2003 by teams studying the artificial element moscovium, which has the atomic number of 115. They noticed that atoms of moscovium broke apart after only a few seconds into atoms of an element with an atomic number of 113. In 2004, Kozuka Morita and a team of scientists at the **RIKEN Nuclear Research Centre** in Japan isolated this element in a different way: they fused bismuth and zinc atoms together.

Glassy carbon (C) has a high resistance to rust.



The Carbon Group

This group contains one non-metal, two semi-metals, and three metals. The non-metal carbon (C) is the main element in all living things. The semi-metals – silicon (Si) and germanium (Ge) – are elements that have the properties of both metals and non-metals, and they are essential in electronics. Two of the metals – tin (Sn) and lead (Pb) – have been used by humans for centuries. Flerovium (Fl), an artificial element, has no known uses.

Atomic structure
Members of this group have four electrons in the outer shell of each atom. These atoms can bond with up to four other atoms.

Physical properties
At room temperature, all natural elements in this set are solid. Flerovium (Fl) is an artificial element, and scientists think it may be a solid.

Chemical properties
All natural elements in this group can react with hydrogen (H). Carbon (C) and silicon (Si) can react with both metals and non-metals.

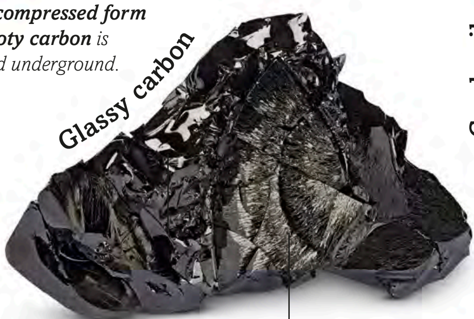
Compounds
These elements react with hydrogen to form compounds called hydrides. Each element can lose up to four electrons when forming compounds.

6
C
Carbon

$-$ 6 $+$ 6 6

State: **Solid**
Discovery: **Prehistoric**

Forms

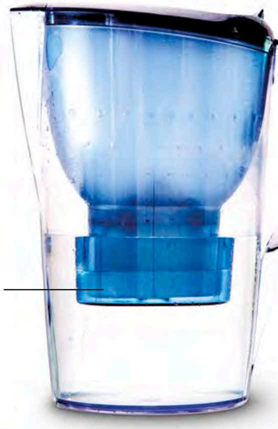


Carbon has the largest number of compounds of any element – with more than nine million known. Carbon is the fourth most common element in the Universe. Each carbon atom can bond to four others, allowing them to form chains and rings. Pure carbon exists in three forms on Earth – **graphite**, **diamond**, and buckminsterfullerene (a structure based on 60 interlinked carbon atoms). Diamond is the hardest substance in nature. It is often used in jewellery. The blades of some **saws** are coated with diamonds, and

Uses

Diamond blade saw

This sharp blade is coated with tiny diamonds.



Water purifier filter

This carbon filter absorbs harmful chemicals in water.

Battery

This battery has a graphite core that carries electric current.

Carbon-fibre bicycle

Sturdy and lightweight frame

This wheel is composed of carbon fibre and some other materials, which make it rigid.

This **strong** but **light** frame is made by fusing together carbon fibres.

Pencil "lead" containing graphite, not lead

Soft graphite leaves a mark when pressed against paper.

Kerosene lamp

This flame is fuelled by carbon-rich oil.

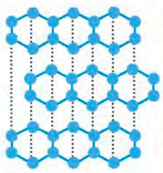
Polythene bag

This flexible plastic material is composed of chains of carbon and hydrogen atoms.

HARD AND SOFT CARBON

Diamond and graphite have different properties because of the arrangement of their atoms – tetrahedrons in diamond, and sheets of hexagons in graphite.

Hard as diamond
The tetrahedron, or pyramid structure, of atoms creates a rigid shape that is equally strong in all directions.



Soft as graphite
Graphite contains layers of carbon atoms that slide over each other easily, as there are only weak forces between them.

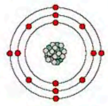
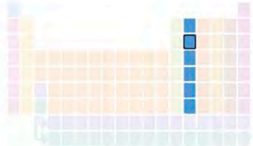
can cut into anything. Only a diamond can cut another diamond. Graphite is much softer, which is why it is used in **pencil "lead"**. It is also used in some batteries. Coal is currently the largest source of fuel for the generation of electricity, but its fumes are also known to have harmful environmental and health effects. Crude oil, natural gas, and **coal** are hydrocarbons (compounds containing only hydrogen and carbon) that occur in nature. They can be used as fuels and as plastics for objects such as **polythene bags**.

PINK DIAMOND

With a mass of only just over 3 g (0.1 oz), this jewel – known as The Sweet Josephine – is one of the largest pink diamonds ever sold. Diamonds are normally colourless forms of pure carbon, and if there is any colour, it comes from tiny amounts of another substance. For example, boron makes the gem appear blue. Strangely, pink diamonds have no impurities, and no-one knows why they are pink.

The Sweet Josephine was cut from raw diamond that is more than 1.5 billion years old. This formed 150 km (93 miles) beneath Earth's surface and was then pushed up by a volcanic eruption, before eventually being dug out at a mine in Australia. Diamonds form when carbon is squeezed and heated to more than 1,000°C (1,832°F). This process rearranges the carbon atoms into a rigid crystal that makes diamond the world's hardest substance. The process also gives diamond the ability to bend light, a property that gives these jewels their glorious sparkle. With the right cut and polish, a diamond can be made into a beautiful gem that is prized throughout the world.

14 Si Silicon

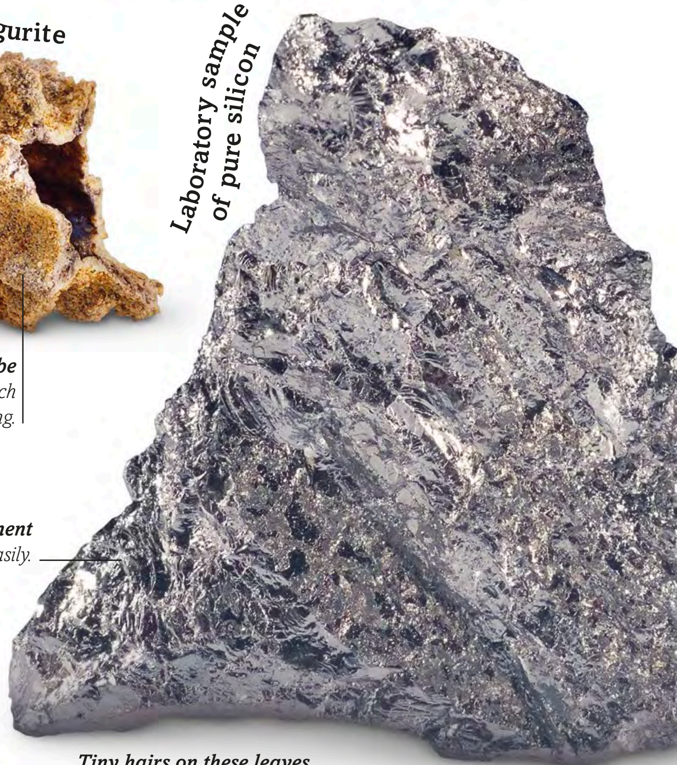
14 14 14

State: Solid
Discovery: 1824

Forms

Fulgurite

This glassy mineral tube *is formed when quartz-rich sand is struck by lightning.*

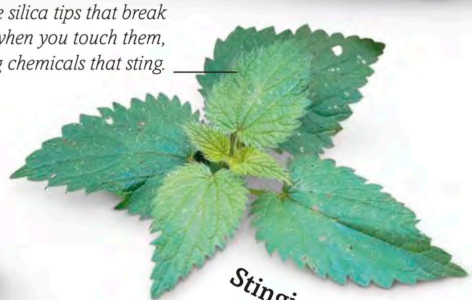


Laboratory sample of pure silicon

The pure element *can shatter easily.*

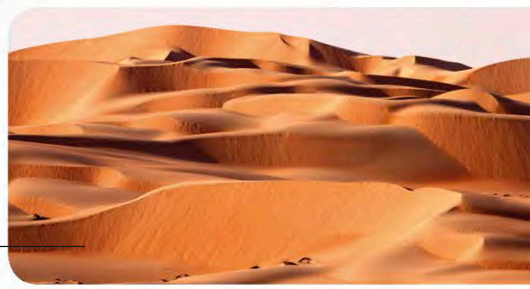
Amethyst

This purple form of quartz *gets its colour from iron impurities.*



Stinging nettle

Tiny hairs on these leaves *have silica tips that break off when you touch them, releasing chemicals that sting.*



Sand

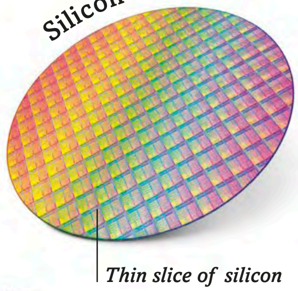
Sand *is mostly tiny grains of quartz that have broken away from rocks.*

About 90 per cent of the minerals that make up Earth's rocks contain silicon, a common element in our planet's crust. Nearly all silicon minerals are compounds of silicon and oxygen, known as silicates. The most common silicate is quartz, the mineral form of silicon dioxide, or silica. It is also the most common substance in **sand**. **Amethyst** is a type of quartz. Quartz deposits are widely found in rocks such as granite and sandstone. A valuable type of silica is **opal**, which is used as a gemstone. The clays used to make pottery and **ceramics** are also silicates.

Uses

Opal ring

Opal is a jewel *containing both silicon oxide and water molecules.*

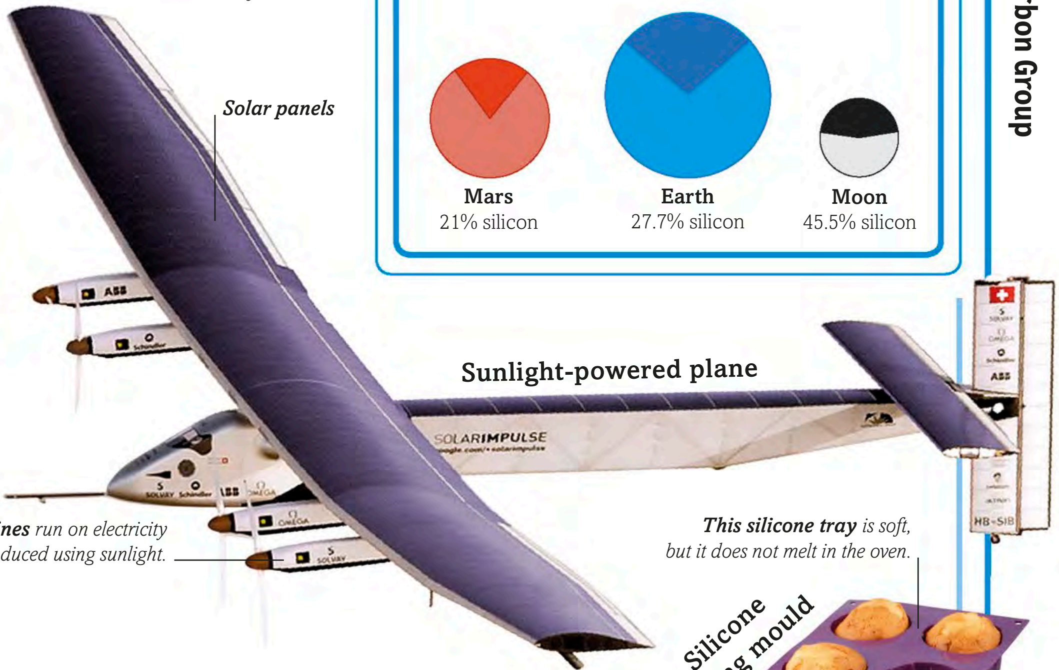


Silicon wafer

Thin slice of silicon

Smokescreen

Screens of silicon-based smoke *can be used in battles.*



Sunlight-powered plane

Solar panels

The engines *run on electricity produced using sunlight.*

SILICON IN SPACE

Earth and Mars contain similar amounts of silicon. This element forms on the outer layer, or crust, of both planets. In contrast, the Moon is almost half silicon. Astronomers think this tells us that the Moon was formed from Earth's surface after an asteroid smashed into our planet about 4.4 billion years ago.

Mars 21% silicon | Earth 27.7% silicon | Moon 45.5% silicon

Ceramic vase

Ceramic *is made of a silicon-based clay that has been shaped and permanently hardened by heat.*

Silicate aerogel in an experiment

Aerogel *conducts the heat from the flame poorly, preventing it from passing to the flower.*

Silicone baking mould

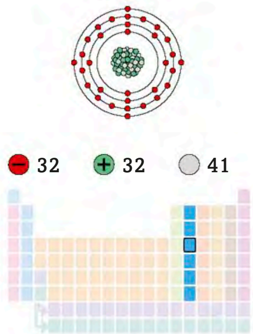
This silicone tray *is soft, but it does not melt in the oven.*

Silicone watch

This silicone band *is flexible and strong.*

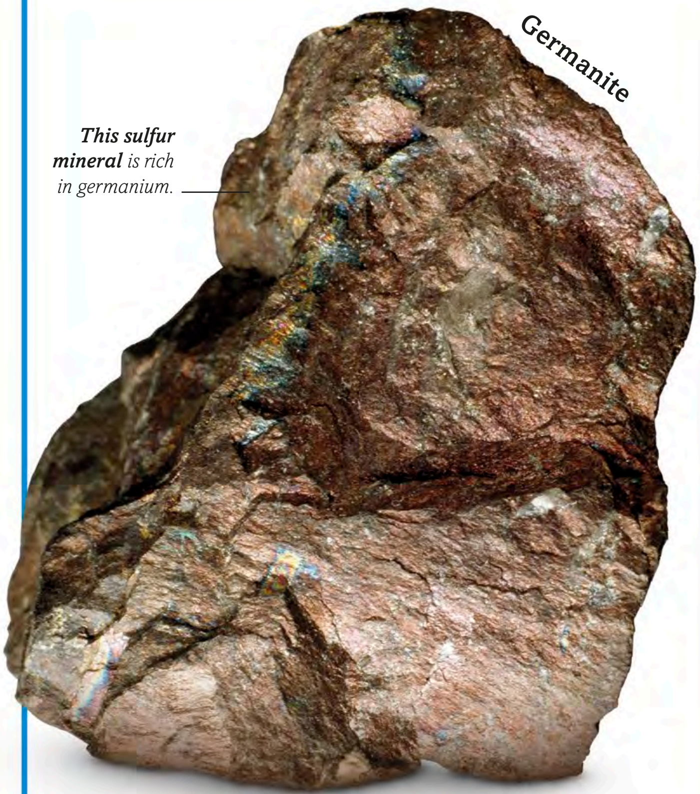
One of the most important uses of silicon is in electronics. Thin slices called **silicon wafers** drive electronic circuits. This versatile element is also used to turn sunlight into electricity in solar panels. Artificial silica is used to create **aerogel**, a lightweight but tough substance that does not conduct heat well. It is used in fire-fighting suits, and prevents flames reaching a firefighter. Another silicon compound is silicone, which can be moulded into any shape, and is used in a wide range of products from **baking moulds** to **watches**.

32
Ge
Germanium



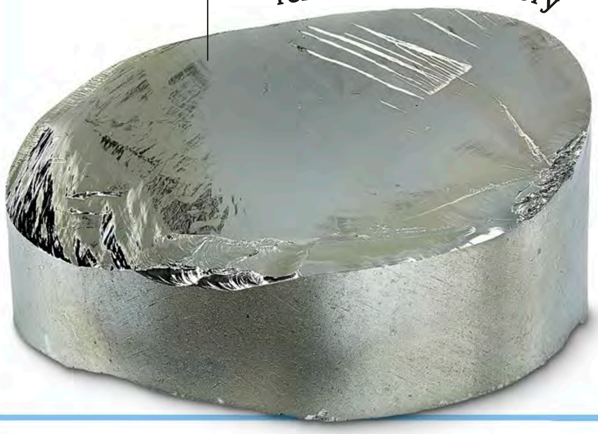
State: Solid
Discovery: 1886

Forms



Germanite

This sulfur mineral *is rich in germanium.*



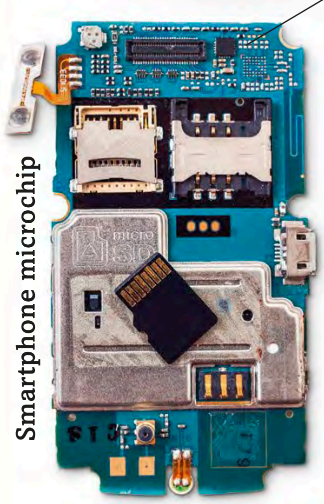
Disc of pure germanium refined in a laboratory

The pure form *is shiny like a metal, but brittle.*

Uses

Camera lens

The germanium oxide in the glass of this lens *bends surrounding light from a large area into the camera.*



Smartphone microchip

This microchip *is made of silicon and germanium.*

Germanium is found in the **atmosphere** of **Jupiter**.

Car with germanium sensor

This car contains a germanium-based sensor *that measures its distance from obstacles.*

This semi-metal is named after the country Germany. It was discovered there in 1886 by chemist Clemens A Winkler, nearly 20 years after Russian chemist Dmitri Mendeleev predicted its existence and properties. **Germanite** is a mineral rich in germanium, but this element is mainly extracted from the ores of silver, copper, and lead. One of its compounds, germanium oxide, is used in wide-angle **camera lenses**. It is also used in some **microchips** and in a number of **car sensors** that aid in navigation.

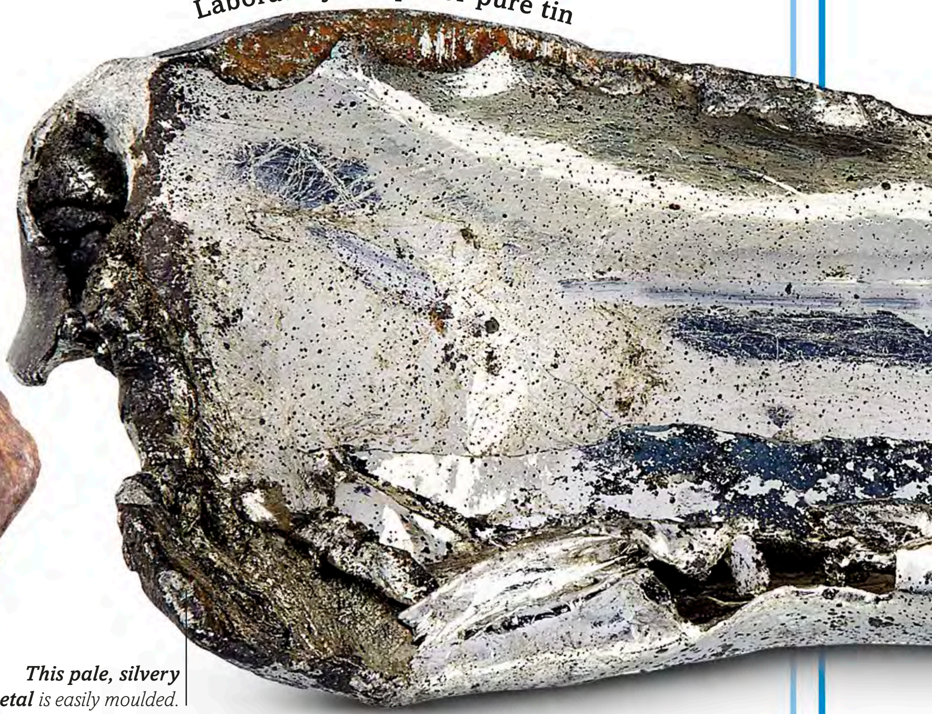
50
Sn
Tin

50 50 69
State: **Solid**
Discovery: **c. 2100BCE**

Forms

Cassiterite

The black colour *of the crystals is due to iron impurities.*



Laboratory sample of pure tin

This pale, silvery metal *is easily moulded.*

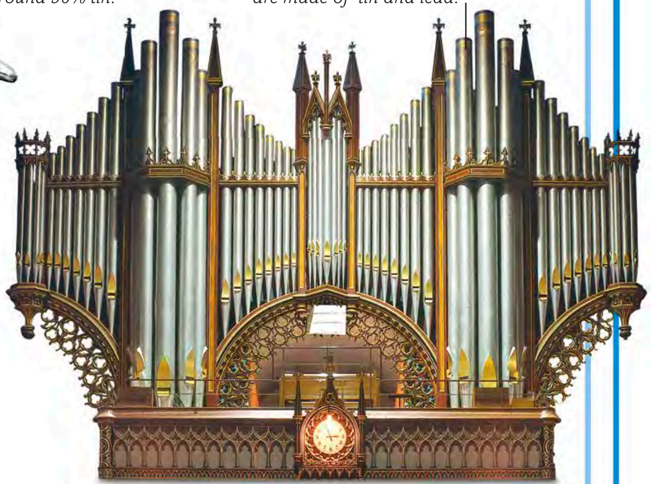
Uses

Watering can

Tin plating *over steel makes the can more resistant to corrosion.*

Pewter figurine

This shiny alloy *contains around 90% tin.*



Pipe organ

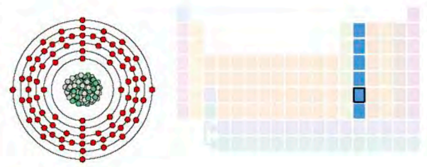
The large pipes *of this organ are made of tin and lead.*

Tin whistle

The tin plating *on this steel whistle prevents rusting.*

Tin was one of the first metals used by humans. As long as 5,000 years ago, tin was mixed with copper to make bronze, an alloy that was stronger than either pure metal. The ore **cassiterite** is the main source of **pure tin**. Uses for tin are many, including plating steel objects, such as **cans**, to stop them corroding. A compound called tin chloride is used for dyeing silks. This metal continues to be used in a variety of tough alloys, including **pewter**, soft solder, and bronze.

82
Pb
Lead



● 82 ⊕ 82 ○ 126
State: Solid
Discovery: Ancient

Forms

Brown crocoite

This soft, crumbly mineral *is made of lead chromate.*

Anglesite

The prism-like crystals *of this mineral contain a lead-sulfur compound.*

Galena

This mineral *has a bright, silvery shine.*

Uses

Lead crystal glass mug

This crystal glass *sparkles more than regular glass because it contains lead oxide.*

Lead pipe

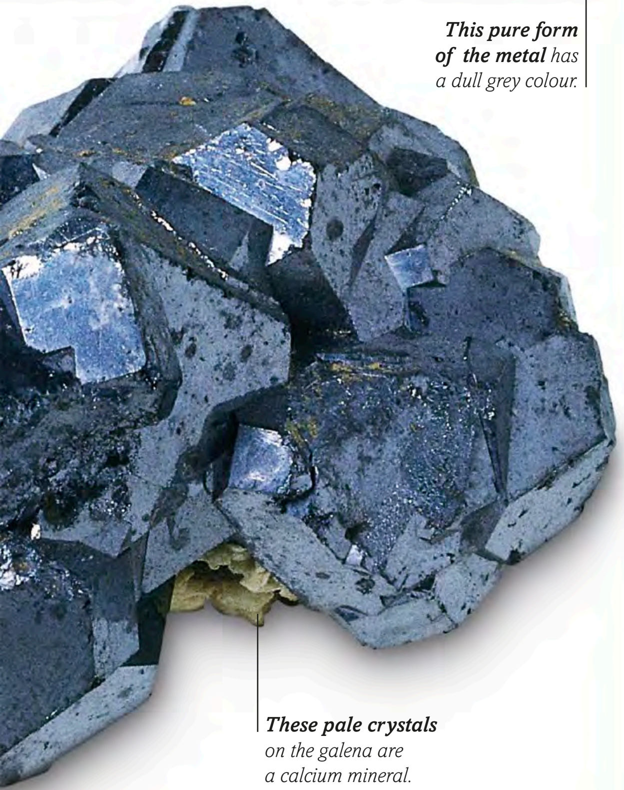
Rust-resistant pipe

For many years, lead and tin were thought to be different forms of **the same metal**.

The chemical symbol for lead, Pb, comes from the Latin word *plumbum*. This is where the word "plumber" comes from: in ancient Roman times, water pipes used in plumbing were made from this soft metal. Lead compounds are found in the minerals **crocoite**, **anglesite**, and **galena** – the main source of **pure lead**. Lead was used far more commonly in the past as an important ingredient in paints, hair-dyes, and insecticides. A common historical use was in **glassware**. It has limited applications today. Lead can

Pure strip of lead refined in a laboratory

This pure form of the metal has a dull grey colour.



These pale crystals on the galena are a calcium mineral.

Flashings, or "lead sheets", cover exposed corners on roofs to make them waterproof.

Flashings

because it absorbs radiation. It is also used in weights for diving, car batteries, and bendy **"flashings"** for sealing roofs. Lead fell out of favour because it turned out to be poisonous.

114
Fl

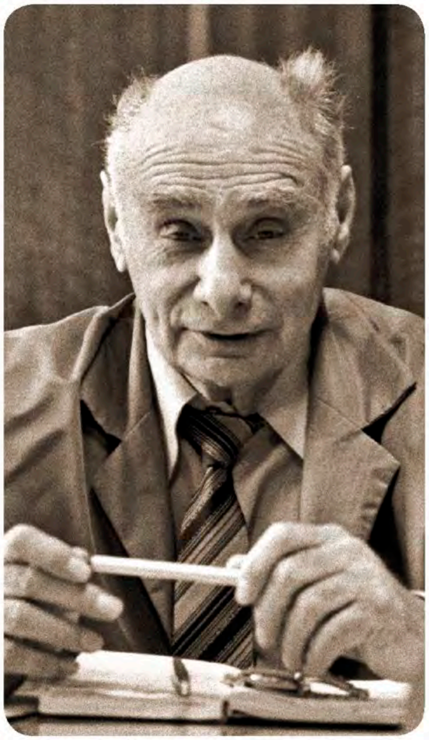
Flerovium

114 114 175

State: Solid
Discovery: 1999

This machine produces flerovium by **smashing together** atoms of calcium and plutonium.

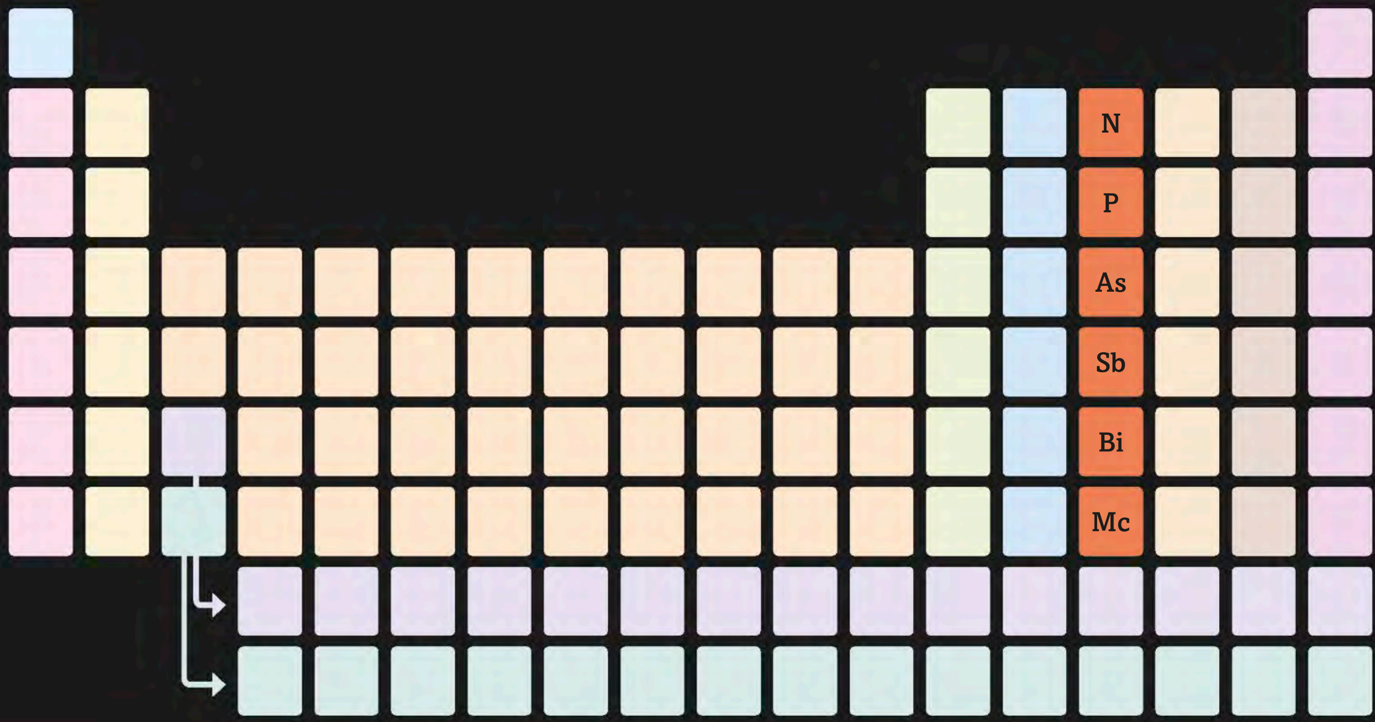
Particle accelerator at Joint Institute for Nuclear Research, Dubna, Russia



Georgy Flerov

Flerovium takes its name from the Russian scientist Georgy Flerov. He founded the **Joint Institute for Nuclear Research** in Dubna, Russia, where this element was first produced in a particle accelerator (a machine in which atoms are smashed together). Flerovium is highly radioactive and its atoms last for only a few seconds before breaking apart.

Molten bismuth (Bi) solidifies to form hopper crystals.



The Nitrogen Group

This group includes different types of natural element – non-metals, semi-metals, and dense metals – as well as moscovium (Mc), an artificial element. The group is also known as “pnictogens”. This derives from the Greek word *pnígein*, which means “to choke” and refers to the potential toxicity of nitrogen (N) in certain forms.

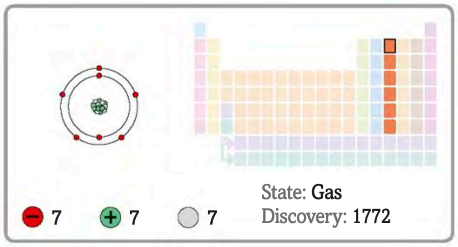
Atomic structure
Members of this group have atoms with five electrons in the outer shell. These atoms can form up to three bonds at the same time.

Physical properties
All the members are solids, except nitrogen (N). The density of elements increases down the group: bismuth (Bi) is 8,000 times denser than nitrogen.

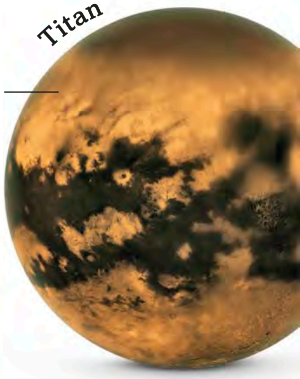
Chemical properties
Phosphorus (P), which exists in two main forms, is reactive, but the others in this group are fairly stable.

Compounds
When reacting with three hydrogen (H) atoms, all members of the group form reactive gaseous compounds called hydrides.

7 N Nitrogen



Forms

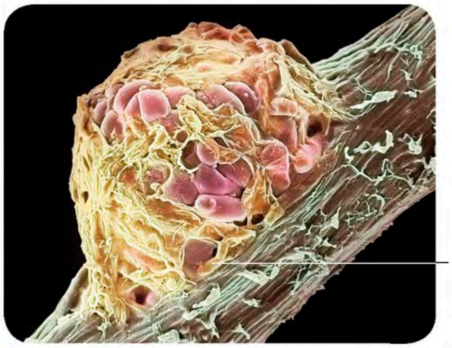


Saturn's largest moon *has an atmosphere containing 48% nitrogen.*

Liquid nitrogen

This clear and colourless liquid *forms when nitrogen is cooled to below –195°C (–319°F).*

This is a naturally *occurring form of sodium nitrate.*



Bacteria living inside plant roots *can take nitrogen from the air for use by the plant.*

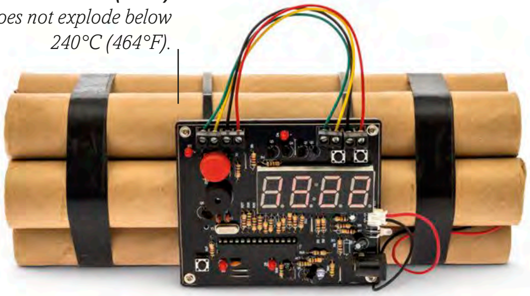
Microscopic image of root nodule

Nitrogen surrounds us all the time because it is the transparent gas that makes up nearly three-quarters of Earth's atmosphere. Since **pure nitrogen** does not react easily, its **liquid form** can be used to freeze and preserve items such as blood and tissue samples.

Nitratine is one of the few minerals rich in nitrogen. Some useful nitrogen compounds can be made by industrial processes. A group of nitrogen compounds is used in explosives, including **TNT** and **nitroglycerine**. When ignited, they explode because the bonds

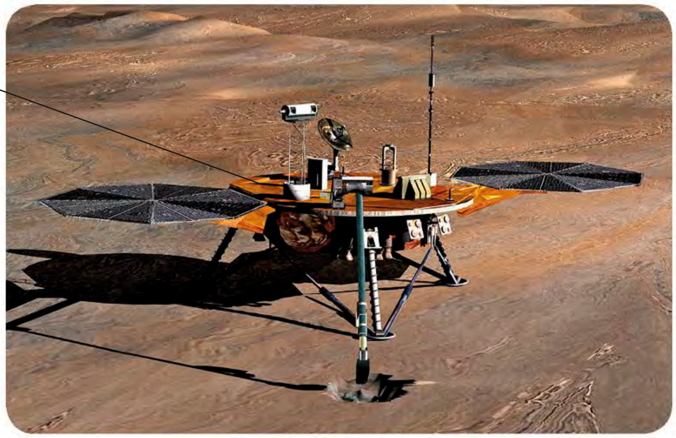
Uses

Trinitrotoluene (TNT) *does not explode below 240°C (464°F).*



TNT

This lander *used 12 hydrazine-powered thrusters to land on Mars.*



Phoenix Mars Lander

Nitroglycerine *can be used to treat heart conditions.*

Nitroglycerine spray

Motorcycles *use nitromethane to fuel their powerful engines.*

Drag bike

These nitrogen-based azo dyes *are often used to colour textiles.*

Textile dye

Superstrong glues *contain small nitrogen compounds that link together.*

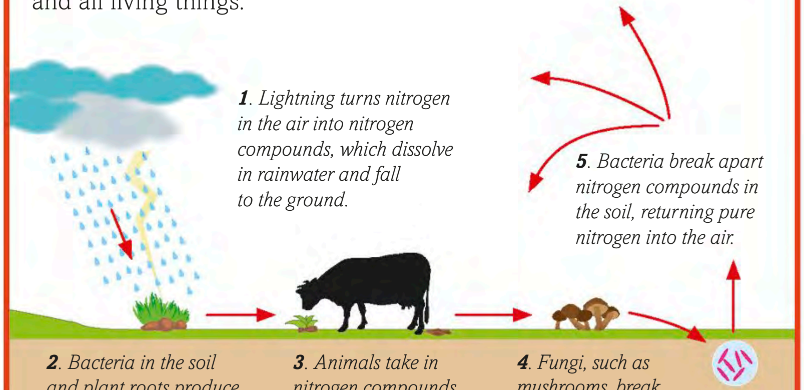
Super glue

These fertilizers *contain compounds called ammonium nitrates that promote growth in plants.*

Nitrogen fertilizer

NITROGEN CYCLE

Nitrogen is essential for life. The nitrogen cycle is a process that constantly recycles nitrogen between Earth's atmopshere and all living things.



1. Lightning turns nitrogen in the air into nitrogen compounds, which dissolve in rainwater and fall to the ground.

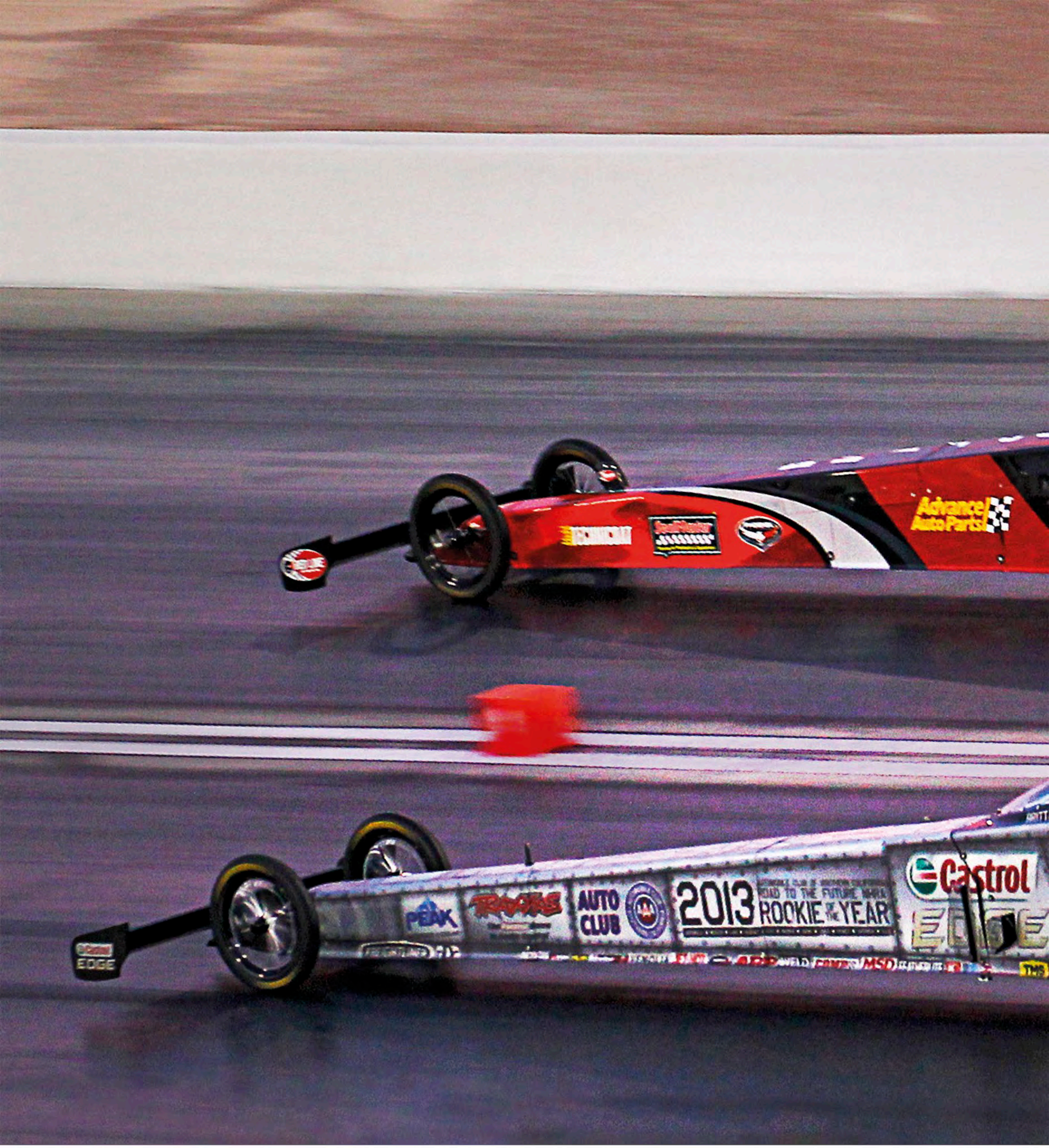
2. Bacteria in the soil and plant roots produce nitrogen compounds from pure nitrogen in the air.

3. Animals take in nitrogen compounds when they eat, and release it in their dung.

4. Fungi, such as mushrooms, break down dead plants and animals, which release their nitrogen compounds back into the soil.

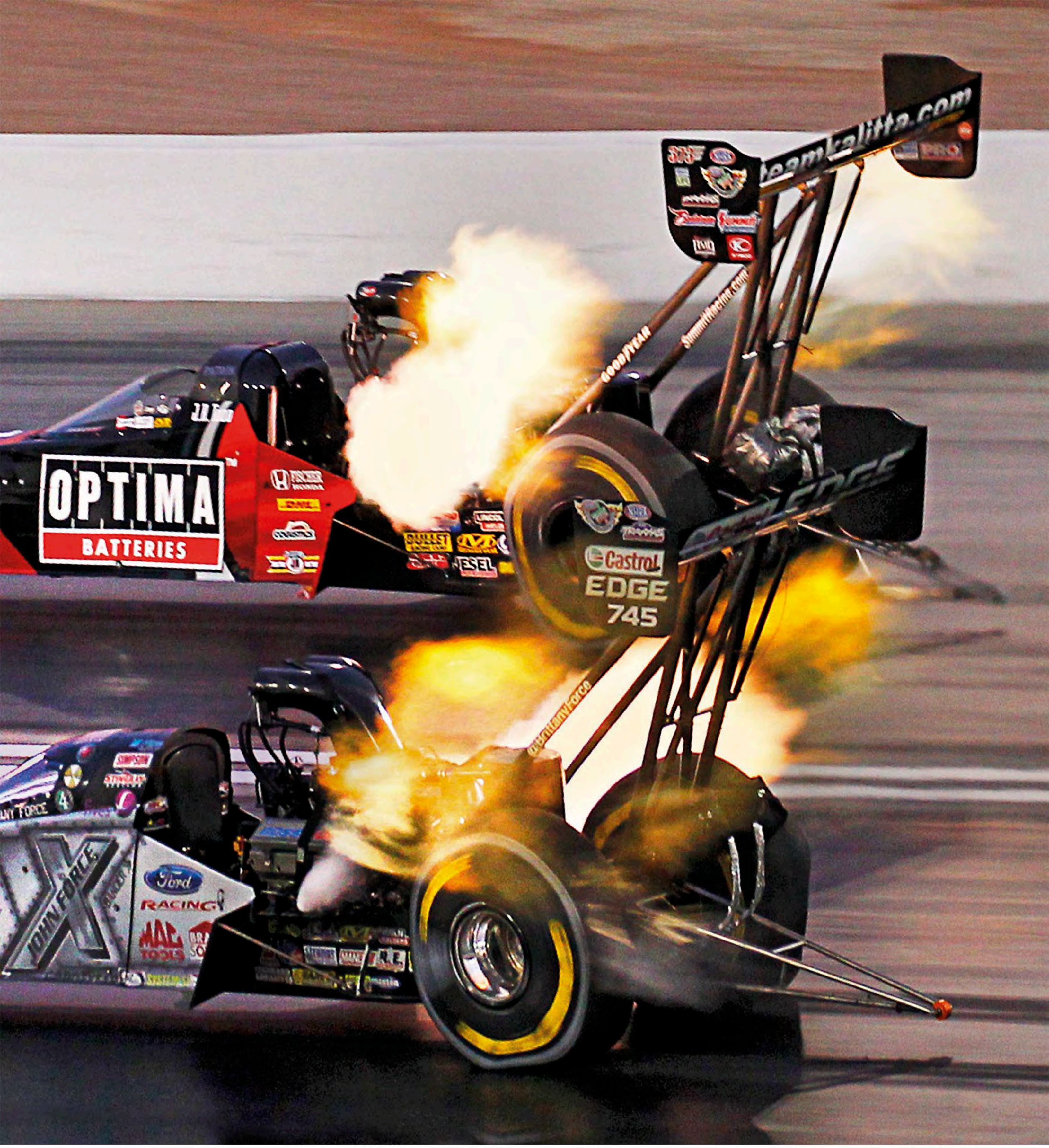
5. Bacteria break apart nitrogen compounds in the soil, returning pure nitrogen into the air.

between nitrogen atoms detach very quickly. Nitrogen fuels, such as nitromethane, are used in **drag bikes**, providing a lot more power than carbon-and-hydrogen only fuels, such as petrol. The compound hydrazine is used in thrusters on spacecraft, such as the **Phoenix Mars Lander**. Some nitrogen compounds are put in **dyes** and **glues**. An industrial technique called the Haber process turns nitrogen and hydrogen gas into ammonia, a liquid commonly used to make **nitrogen fertilizers**. When mixed with soil, these fertilizers boost plant growth.



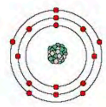
DRAG RACING

Zooming along a dead straight track, these all-powerful dragsters accelerate all the way to the finish line. They contain massive engines filled with an extra-powerful fuel called nitromethane, which is often shortened to “nitro”. Burning eight times faster than regular petrol used in most cars, this super fuel can push dragsters to speeds in excess of 480 km/h (300 mph).

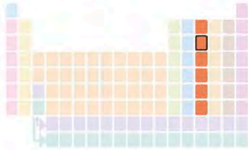


Nitromethane contains carbon, hydrogen, and nitrogen, but it is the latter element that really gives this fuel its immense power. During the process of combustion – when oxygen is mixed with the fuel in the race car's mighty engine – nitromethane burns so violently that nitrogen escapes from the fuel and returns to its pure form. This chain of events leads to a release of energy, which propels the dragsters to breakneck speeds. Although these races are an incredible spectacle to behold, driving using nitromethane can be dangerous due to the explosive nature of nitrogen when used in this way: drag racers are taking a risk to win.

15
P Phosphorus



15 15 16



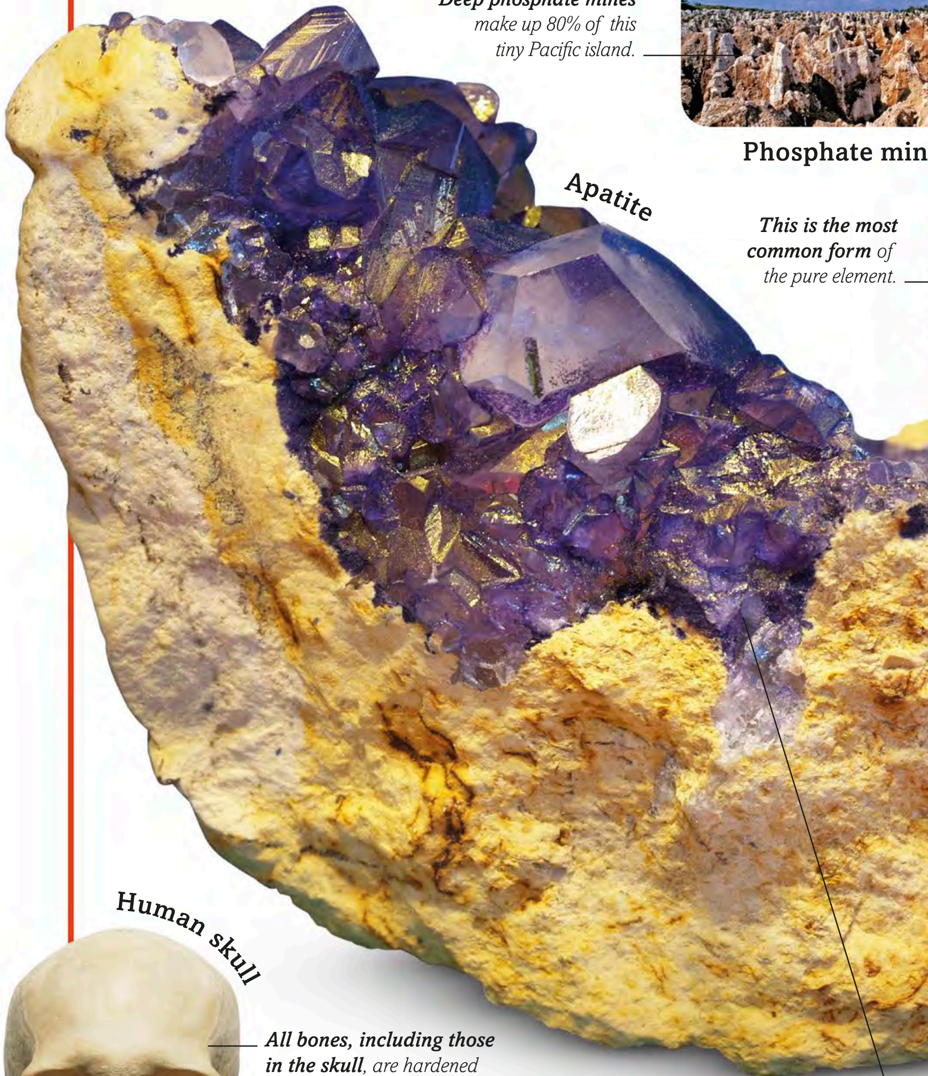
State: Solid
Discovery: 1669

Forms

Deep phosphate mines make up 80% of this tiny Pacific island.

Phosphate mining in Nauru

Apatite



This purple colour of the crystals is due to metal impurities.

Red phosphorus

This is the most common form of the pure element.

White phosphorus

This element remains stable in water, but catches fire on contact with air.

Chunk of violet phosphorus

This form of phosphorus is made in a laboratory by heating red phosphorus.

Human skull

All bones, including those in the skull, are hardened by calcium phosphate.

Tuna

This fish is rich in phosphorus.

Phosphorus was accidently discovered by German alchemist Hennig Brand. In 1669, in his quest for the mythical Philosopher's Stone (a material some believed could turn any metal into gold), he boiled a large pot full of urine for days. This produced a mysterious glowing substance, which he called phosphorus, meaning "giver of light". Phosphorus is the first element to have a discoverer with a recorded name. It is never pure in nature, and occurs in different minerals. Phosphorus has several flammable,

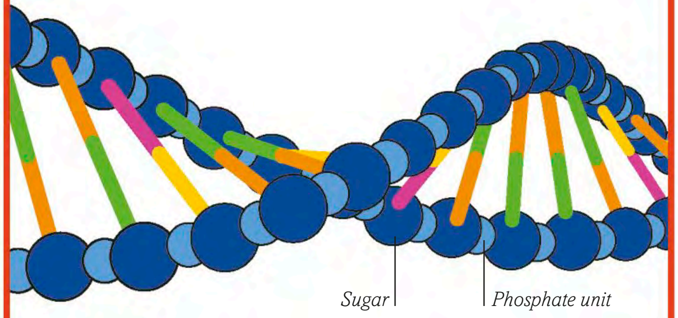
Uses

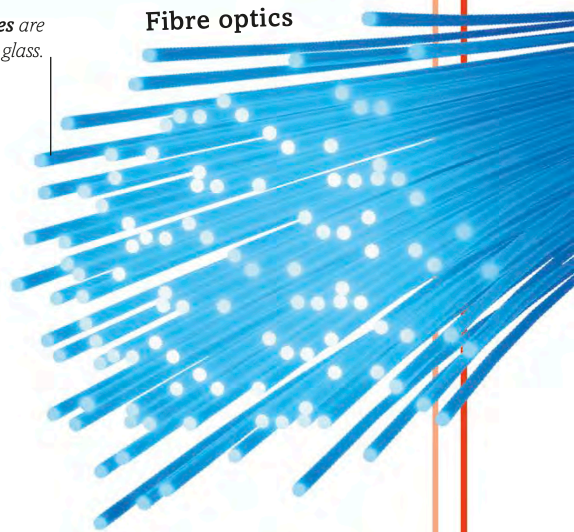
This light, strong china contains calcium phosphate.

China tea set

LIFE'S BUILDING BLOCKS

DNA – short for deoxyribonucleic acid – is like a mini database packed with instructions telling your body how to work properly. It consists of a chain of molecules and looks like a twisted ladder called a double helix. The edges are sugar molecules linked together by units containing phosphorus.





Fibre optics

These flexible fibres are composed of phosphate-rich glass.

Safety match box

The striking surface on the sides of the box contains phosphorus, which ignites the match upon contact.

Fire extinguisher

Spraying ammonium phosphate over burning material cuts off its supply of oxygen. This extinguishes the fire.

Pesticides

Spraying crops with phosphates kills pests, such as insects.

Fertilizer

This fertilizer contains ammonium phosphate to boost plant growth.

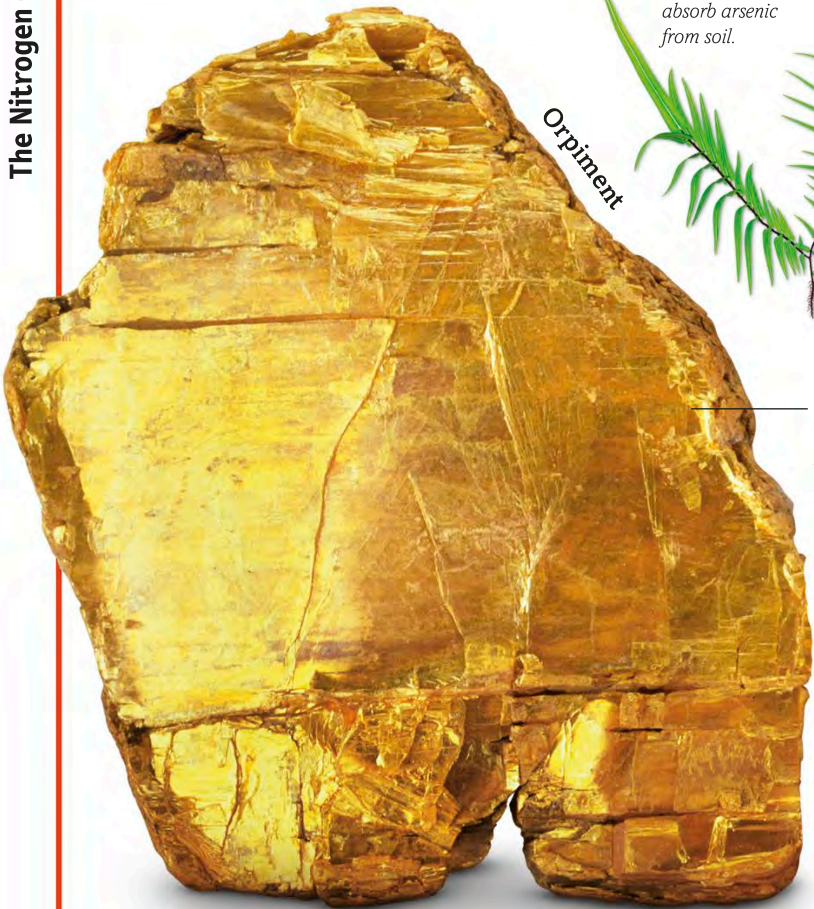
solid forms, including **red**, **white**, black, and **violet**. The glow seen by Brand was caused by white phosphorus reacting with oxygen. Phosphorus is mainly found in **phosphate** minerals (in which phosphorus links to oxygen), such as **apatite**, its main ore.

Phosphates are present in **fine china**, and are an important ingredient in **fertilizers**. The strips on the sides of **safety match boxes** contain pure phosphorus. More complex phosphorus compounds used in **pesticides** are poisonous.

33
As
Arsenic

33 | 33 | 42
State: Solid
Discovery: c. 1250

Forms


Orpiment

Until the 1800s, this mineral was powdered for use in paints.


Chinese brake fern

These leaves *absorb arsenic from soil.*


Pure arsenic refined in a laboratory

Metallic shine


Realgar

This ore *is found in hot volcanic springs.*

Uses

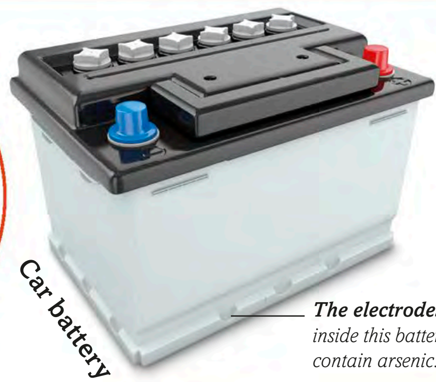

Bullets

This tip *is an alloy of arsenic and lead.*


Rat poison

This poisonous arsenic compound *kills rats.*

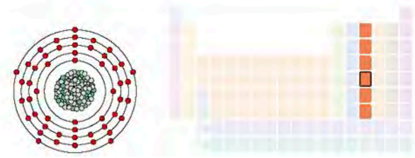
When heated, arsenic **doesn't melt**, instead it **turns into a gas**.


Car battery

The electrodes *inside this battery contain arsenic.*

Arsenic is often called the "king of poisons". Every form of arsenic – either pure or in a compound – is poisonous to animals. In fact, arsenic poisons have been used for centuries. This semi-metal is found in several minerals with striking colours, including **orpiment**. Naturally occurring **pure arsenic** has a shiny, grey colour. Arsenic compounds are used in making some **rat poisons**. The leading use of arsenic today is for strengthening lead. This is done by mixing arsenic with lead to create a tough alloy that is often used in **car batteries**.

51 Sb Antimony

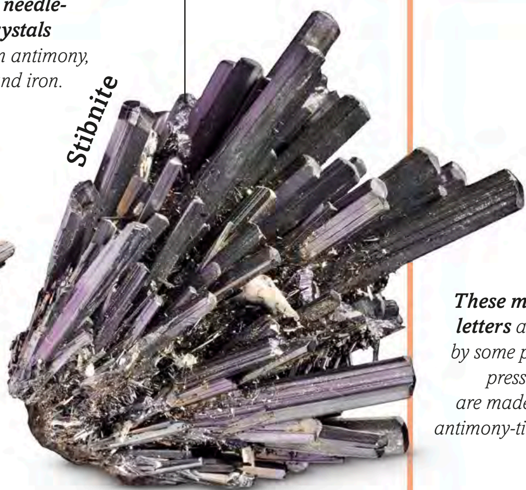


State: Solid
51 51 71 Discovery: c. 1600 BCE

Forms

Jamesonite

These needle-like crystals contain antimony, lead, and iron.



Stibnite

This mineral tarnishes on contact with air.

Pure antimony crystals refined in a laboratory

This silvery semi-metal is hard but brittle.

Uses

These metallic letters are used by some printing presses, and are made of an antimony-tin alloy.

Printing press metal type

These matches with antimony in the tip burn brighter than the ones without it.

Safety matches

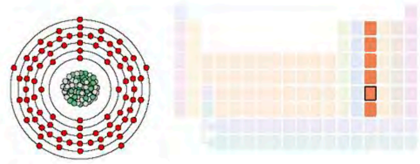
Egyptian kohl

Kohl is a dark eyeshadow.

Kohl makes it **easier to see** in strong sunlight.

Antimony gets its name from the Greek word *anti-monos*, meaning "not alone". This may refer to the fact that the element is never found pure in nature, but is always found combined with heavier metals, such as lead. The element's symbol, Sb, comes from *stibium*, the Latin word for kohl, a form of eye make-up. The mineral ore **stibnite** is the largest source of **pure antimony**. Its pure form is mostly used to make hard alloys, such as that in the **metal type** used by some printers. Ancient **Egyptian kohl** was made from powdered stibnite.

83
Bi
Bismuth



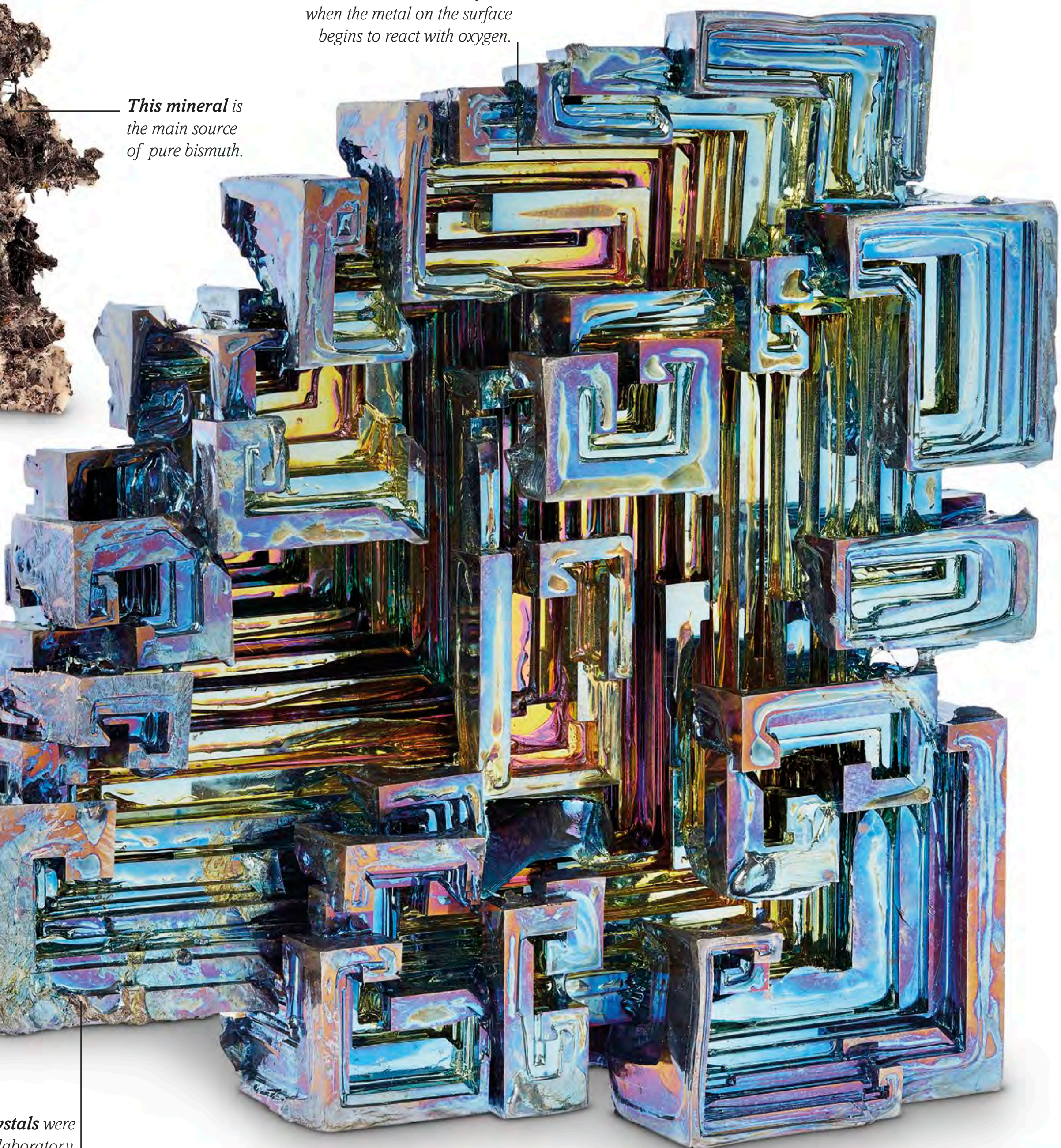
83 83 126
State: Solid
Discovery: c. 1500

Forms

***This mineral** is the main source of pure bismuth.*

Bismuthinite

In Earth's crust, bismuth is about **twice as abundant as gold**.



***These rainbow colours** form when the metal on the surface begins to react with oxygen.*

Hopper crystals refined in a laboratory

***These bismuth crystals** were produced in a laboratory.*

Bismuth is a radioactive element but its atoms are relatively stable and last for millions of years. People have known about bismuth for centuries. The Incas of South America added it to weapons made of the alloy bronze to harden them, while ancient Egyptians used a bismuth mineral to make their cosmetics glittery. Pure bismuth forms an oxide in air that is seen as colourful crystals called **hopper crystals**. This element is very brittle and has few uses when not in a compound form. Yellow bismuth

Uses

This cold box uses a compound called bismuth telluride, which becomes cold when electrified, and keeps items cool.

Portable refrigerator

***This nail polish** gives a pearly effect because of bismuth compounds.*

Yellow cosmetics

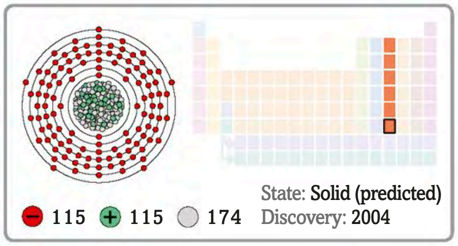
***This medicine** contains a bismuth compound that helps settle an upset stomach.*

Digestive medicine

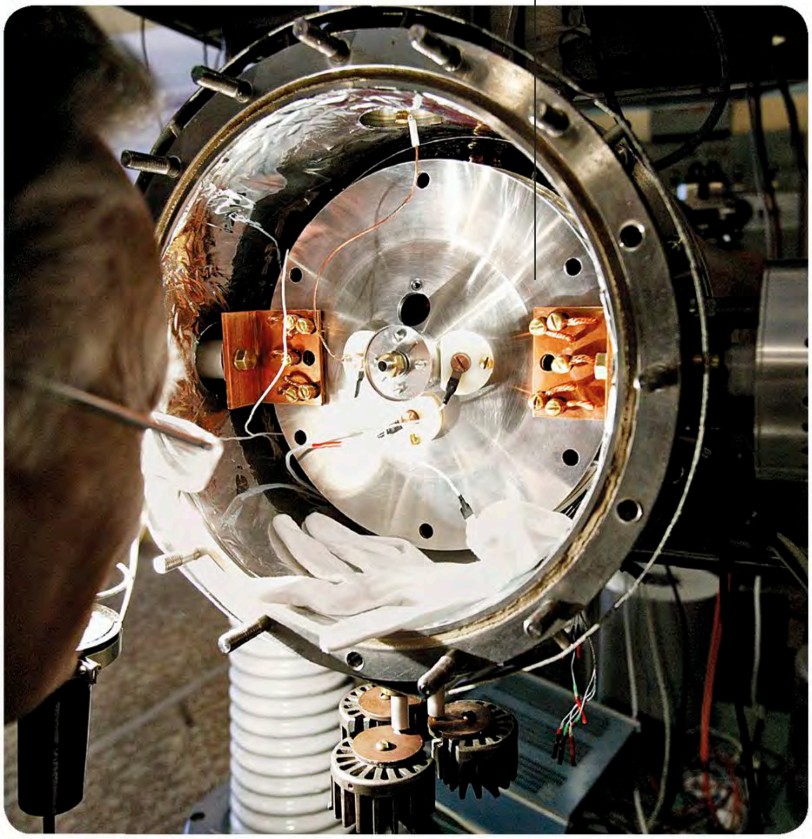
Unlike most elements, bismuth's liquid state is heavier than its solid.

pigments are used in paints and **cosmetics**, while several bismuth compounds are also in **medicines**. An alloy of bismuth and tin is an ingredient in fire sprinklers.

115 Mc Moscovium

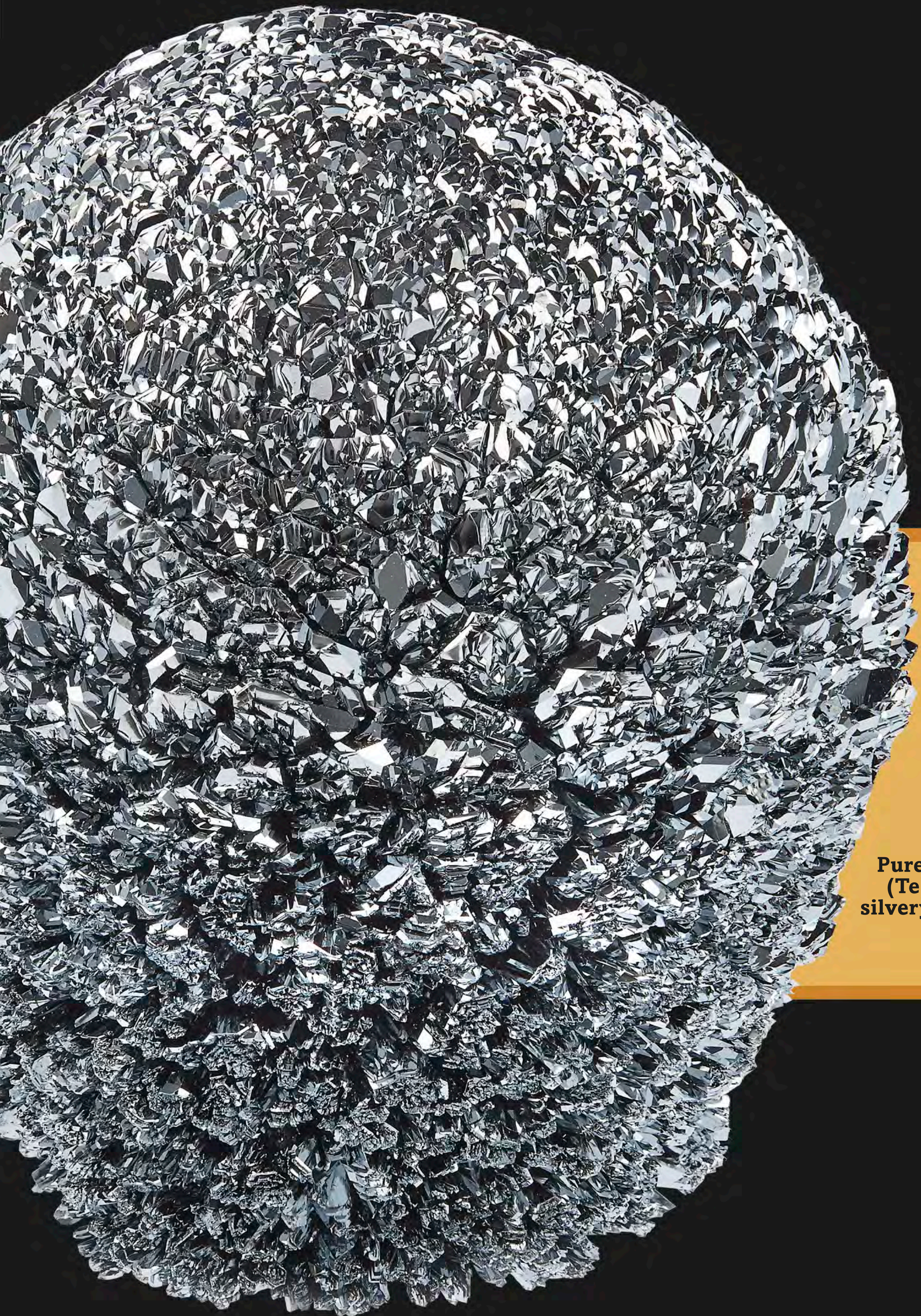


***This is one of the machines** in this research centre.*

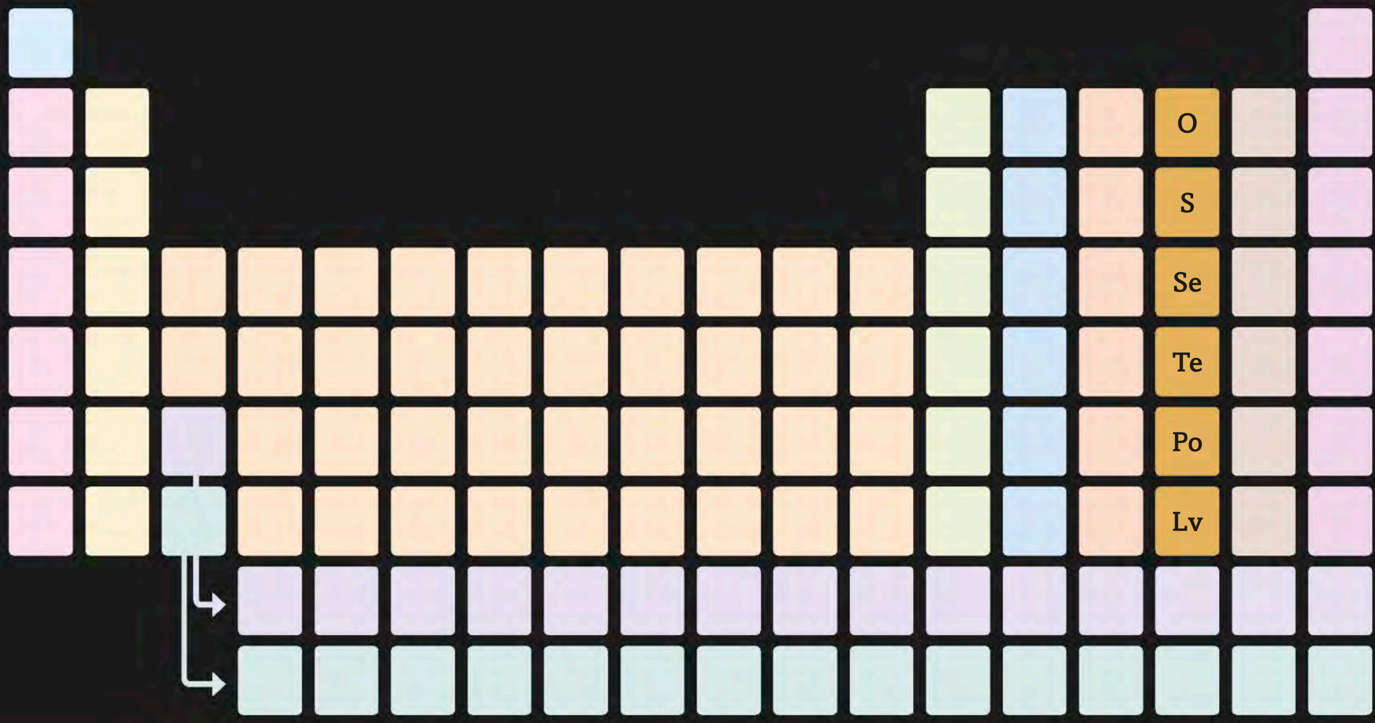


Joint Institute for Nuclear Research, Dubna, Russia

Only about a hundred or so atoms of this heavy, artificial element have been made. Moscovium was first created at the **Joint Institute for Nuclear Research** in Dubna, Russia. A team of Russian scientists, led by Yuri Oganessian, created this element by smashing americium atoms with parts of calcium atoms. It is named after the Russian capital city of Moscow. This element is extremely radioactive, and its atoms break up within a fraction of a second. Scientists think that moscovium would be a dense, metallic solid but with such small samples, they can only measure how big the atoms are before they break up.



Pure tellurium (Te) can form silvery crystals.



The Oxygen Group

This group does not include any natural metals. The first two members, oxygen (O) and sulfur (S), are non-metals widespread in nature. The remaining three natural elements are semi-metals. Only the artificial member, livermorium (Lv), is thought to be a metal, but chemists don't really know for sure.

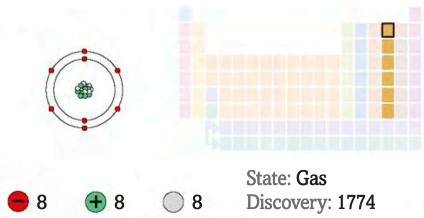
Atomic structure
All members have six electrons in the outer shell of each atom. This electron structure makes these elements highly reactive.

Physical properties
The members of this group are solids, except oxygen (O), which is a gas at room temperature. The density of the elements increases down the group.

Chemical properties
The reactivity of these elements decreases down the group. Oxygen is always involved in the process of combustion.

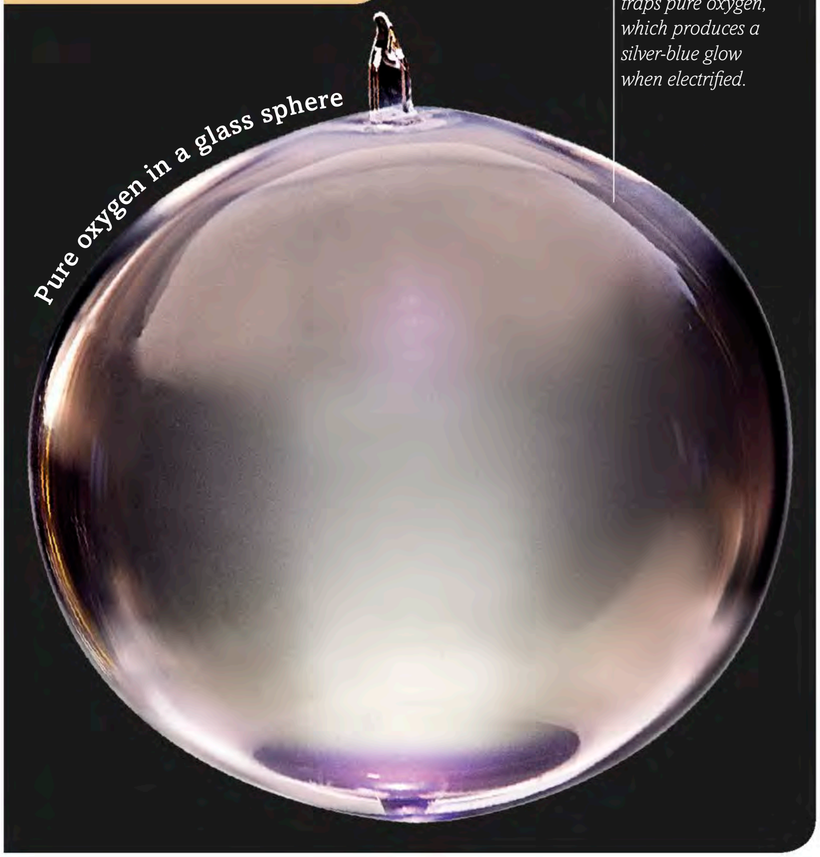
Compounds
These elements can form compounds with each other. They all react with carbon (C) to form compounds, some with strong smells.

8 O Oxygen



State: Gas
Discovery: 1774

Forms



Pure oxygen in a glass sphere

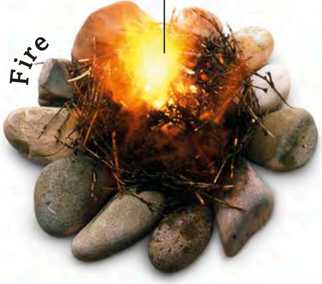
This glass sphere *traps pure oxygen, which produces a silver-blue glow when electrified.*

Streaks of light *adorn the sky as atoms of oxygen in the air are hit by a stream of particles blasting from the Sun.*

Northern lights

Plants *release oxygen in sunlight.*

Flames *are produced when oxygen reacts with fuel, such as wood.*



Fire

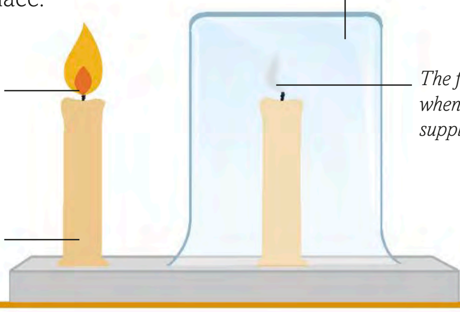
Sunflowers

Each water *molecule has two atoms of hydrogen and one of oxygen.*

Water

WHAT IS COMBUSTION?

Combustion is a chemical reaction that produces heat and light. Oxygen is essential for combustion to take place.



A beaker is placed over a candle, starving the flame of oxygen.

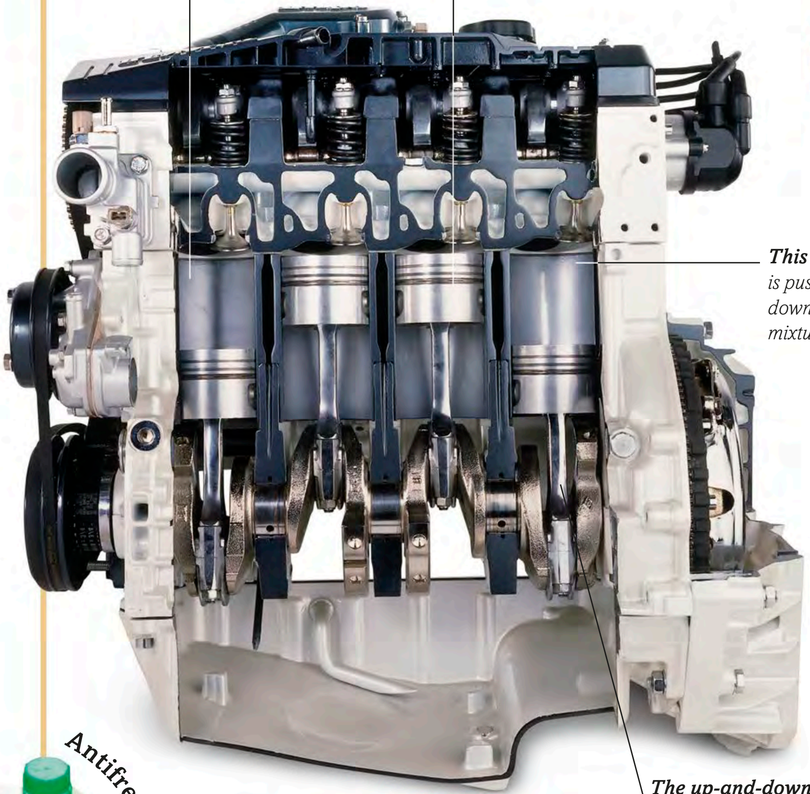
The flame is steady in the presence of oxygen.

The flame goes out when the oxygen supply is cut off.

Candle wax is made of a flammable carbon compound, which acts as a fuel.

Oxygen is the most common element in Earth's crust. Oxygen and its compounds make up half of all rocks and minerals on our planet. In the atmosphere, **pure oxygen** makes up around one-fifth of the air. This element is a transparent gas. Life on Earth depends on oxygen for survival. Animals breathe in air to collect the oxygen in it. Our bodies' cells then use that oxygen to break apart sugars to release energy, which powers our bodies. Another process that involves oxygen is the burning reaction called combustion, in which oxygen

Uses



This cylinder *takes in oxygen along with the fuel.*

The piston *then squeezes the mixture of oxygen and fuel.*

This piston *is pushed down when the mixture explodes.*

The up-and-down motion of the pistons *makes the wheels of a car spin.*

Internal combustion engine

Hot steel *may have impurities that are burned away using pure oxygen.*

Steelmaking

The oxygen in this cylinder *can last for up to 30 minutes.*

Scuba diver

This rocket *carries liquid oxygen that mixes with the fuel to produce hot gases, which help the rocket lift off.*

Atlas V rocket

Antifreeze

This liquid *contains an oxygen compound that prevents water from freezing in an engine.*

Oxygen is **colourless** as a gas, but looks **pale blue** as a liquid.

Mountaineers *have to adjust slowly to changing levels of oxygen as they climb higher.*

Mountaineer with oxygen supply

Medical oxygen cylinder

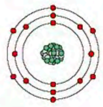
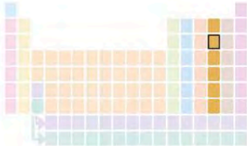
The oxygen in this cylinder *is given to patients in controlled amounts.*

Welding torch

This flammable gas-oxygen mixture *burns hot enough to melt metal.*

reacts with a fuel and produces **fire**. Oxygen is also used up when it reacts with other elements to form compounds called oxides. However, it is replenished by **plants** through a process called photosynthesis, which releases fresh oxygen. Car **engines** are powered by the combustion of petrol or other fuels. Oxygen is also useful in the **making of steel**. Tanks of oxygen let **mountaineers** breathe easily in environments that have low levels of this gas. Rockets, such as the **Atlas V**, carry liquid oxygen to burn fuel in the absence of air in space.

16
S
Sulfur

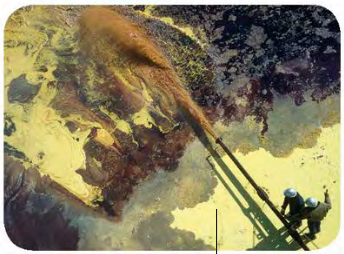



$-$ 16 $+$ 16 16
State: Solid
Discovery: Prehistoric

Forms

Natural sulfur

These yellow sulfur crystals *often attach to volcanic mud.*

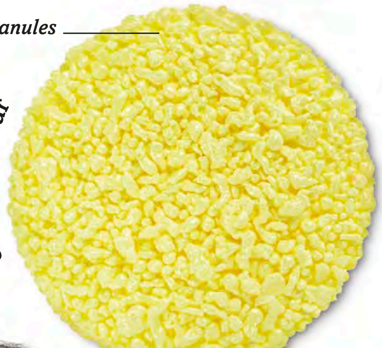


Liquid sulfur

Hot liquid sulfur *is pumped up from an underground mine.*

Celestine

This grey-blue crystal *contains a sulfur compound called strontium sulfate.*



Laboratory sample of pure sulfur

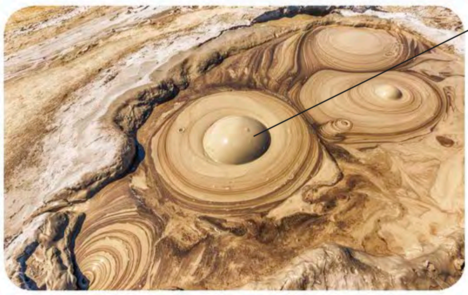
Soft, brittle granules

Skunk

Skunks *release a foul spray that contains three kinds of sulfur compounds.*

Onions

Cut onions *release sulfur compounds that make our eyes water.*



Mud volcano

Hydrogen sulfide bubbles *form in volcanic mud.*

Known since ancient times, sulfur is one of the few non-metals that can be found pure in nature. This yellow, crystalline element is found in large amounts near volcanic craters. Another name for sulfur is "brimstone", which refers to the way its crystals burn, melting into a blood-red liquid. In some religions, brimstone is thought to be the fuel that burns in the underworld. **Pure sulfur** is extracted from underground deposits using hot water. The hot **liquid sulfur** is then pumped to the surface. This element is a common ingredient in many

Uses

Vulcanized tyre

Vulcanized rubber – made by heating sulfur with natural rubber – is weatherproof.

Preserved dried fruits

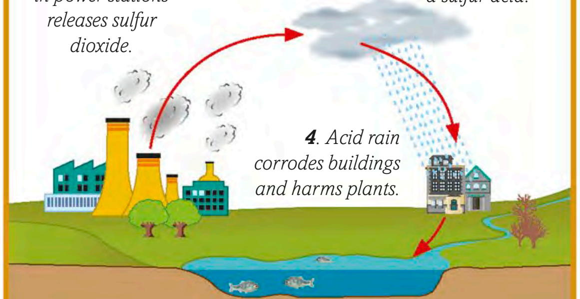
Some dried fruits are preserved using powder containing a sulfur compound.

Sulfur candle

When burned, sulfur in this candle drives away pests.

ACID RAIN

Sulfur dioxide gas produced by burning fuel dissolves in rain water, making a sulfur acid. This falls to the ground as acid rain.



1. Burning coal in power stations releases sulfur dioxide.

2. The wind carries pollutants.

3. Sulfur dioxide mixes with water in clouds and forms a sulfur acid.

4. Acid rain corrodes buildings and harms plants.

5. Acid rain changes soil chemistry.

6. It also makes rivers and lakes acidic.

Lead acid battery

This battery contains strong sulfuric acid.

Skin cream

Creams that contain sulfur compounds can disinfect skin.

Titan arum

This plant emits a rotting smell to attract meat-eating insects.

Penicillin pills

Some antibiotics contain sulfur compounds that kill harmful bacteria.

Acid rain **destroys forests** by removing nutrients in the soil and in the leaves.

Sulfur acid rain damage

This limestone sculpture has been weathered by acid rain.

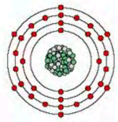
minerals, such as **celestine**. Many sulfur compounds smell bad. For example, the rotten-egg smell of volcanic pools is due to hydrogen sulfide gas. Other examples include **skunk** spray, the gaseous substance emitted by chopped **onions**, and the odour of the **titan arum** flower. There are many uses for this non-metal. Its compounds can harden natural rubber for use in **tyres**, preserve **dried fruits**, and make strong **battery** acids. The element has anti-bacterial properties and is used in antibiotic medicine, such as **penicillin**.

DANAKIL DEPRESSION This hot spring in Africa's Danakil Depression is surrounded by a yellow crust of pure sulfur. The sunken region between Ethiopia and Eritrea in East Africa is a wild volcanic area, packed with erupting craters, arid deserts, boiling mud, and pools with unusual colours caused by the presence of sulfur and many mineral salts.

At more than 100 m (330 ft) below sea level, the Danakil Depression is one of the lowest points on Earth's surface. This area receives little or no rainfall and the weather is hot and dry, with temperatures soaring above 50°C (120°F). The scalding green water of the springs inside the depression contains pure sulfur as well as a toxic sulfur compound called sulfuric acid. As the water evaporates, sulfur deposits build up around the edges of the pools, making beautiful shapes across the vast landscape. Tourists visit to marvel at the remarkable sights at Danakil, even though the inhospitable conditions in the area give it the title of the "cruellest place on Earth".

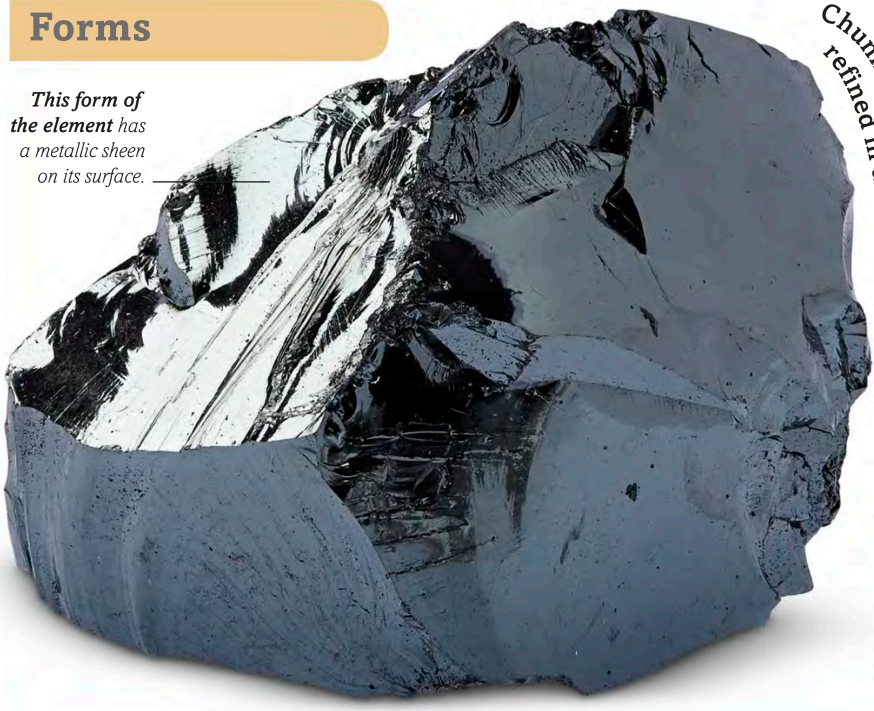
34
Se

Selenium




34 34 45
State: Solid
Discovery: 1817

Forms



Chunk of pure grey selenium refined in a laboratory

***This form of the element** has a metallic sheen on its surface.*

Brazil nuts

***These nuts** are the richest food source of selenium.*

Berzelianite

***These dark areas** contain selenium and copper.*

Uses

Calculator

***This calculator** is powered by a solar cell made of selenium and nickel.*

Anti-dandruff shampoo

***A selenium compound** in this shampoo treats dandruff.*

Ceramic vase

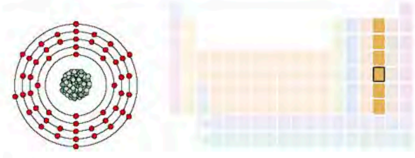
***This bright colour** comes from the red selenium in the glaze.*

Photocopier

***Many office photocopiers** use selenium in powdered form.*

Selenium is named after Selene, the Greek goddess of the Moon. This element is a semi-metal and so has the properties of both metals and non-metals. Selenium has two main pure forms: **grey selenium**, which is a hard substance, and red selenium, which is a soft powder. The most common use of selenium is as an ingredient that provides colour in glass and **ceramics**. Selenium is sensitive to light, so it is used in solar cells that convert sunlight into electricity. It is also utilized in **photocopy machines**.

52 Te Tellurium



52 | 52 | 76

State: Solid
Discovery: 1783

Forms

Melonite

This ore *is a soft but dense solid.*

Sylvanite

This metallic crust *contains tellurium, gold, and silver.*

Pure tellurium crystals refined in a laboratory

This semi-metal *can form silvery white crystals.*

Uses

Fibre optics

These glass fibres *contain tellurium.*

Red-tinted glass bottle

This deep red colour *comes from adding tellurium.*

Tellurium **protects** bronze **from corroding** easily in air.

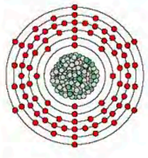
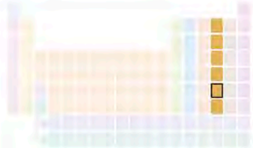
Topaz solar farm, California, USA

The solar panels *are linked to power cells containing tellurium.*

Tellurium is one of the 10 rarest elements on this planet. It gets its name from the Latin word *tellus*, which means Earth. This element is often found as a compound with another element, such as the metal nickel, as in the case of the ore **melonite**. Tellurium is also produced as a waste product when lead and copper are refined. **Pure tellurium** can take on two forms: a shiny, metallic solid or a brown powder. This element is mainly used in the glass of **fibre optics**, which carry high volumes of information much faster than copper cables.

84
Po

Polonium

84 84 125
State: **Solid**
Discovery: **1898**

Forms

This uranium ore contains **0.0000001 per cent** polonium.

Uraninite

This mineral *contains uranium atoms that break apart to form atoms of polonium.*

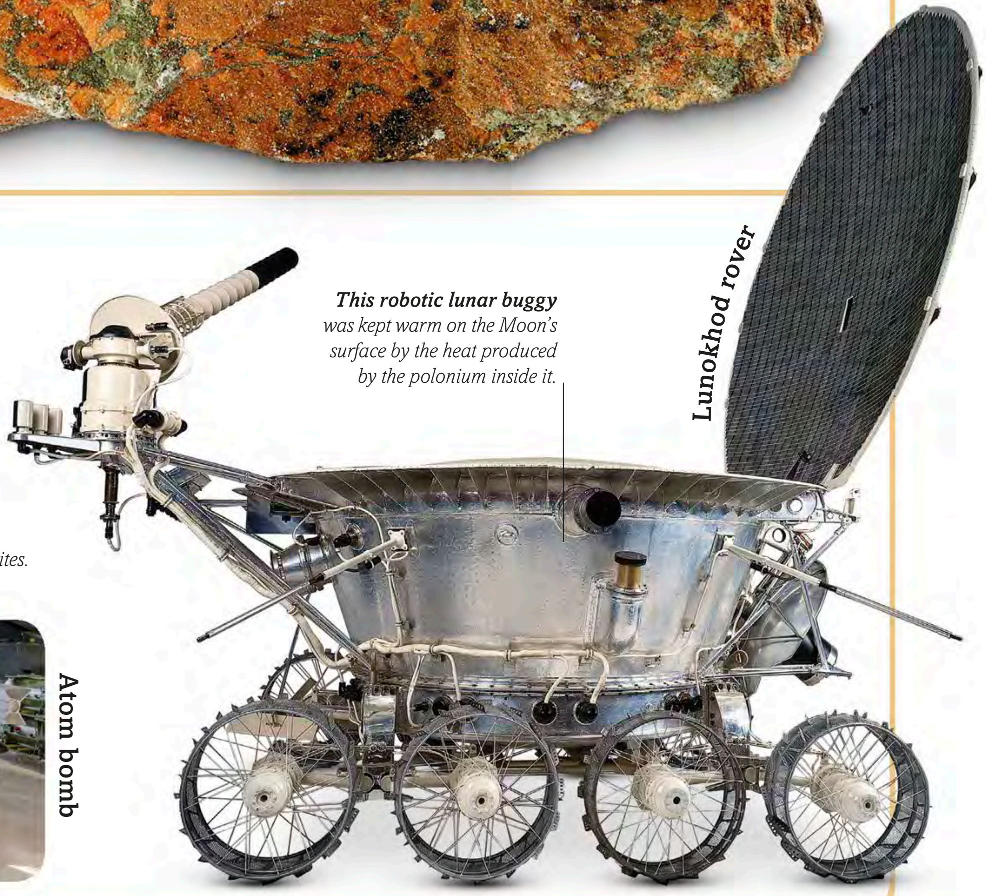
Uses

Anti-static brush

This brush *is used to remove static electric charge from camera lenses and music records.*

This bomb *can be detonated when the polonium inside it ignites.*

Atom bomb

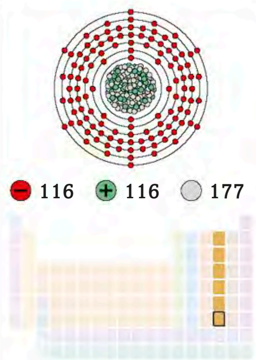


Lunokhod rover

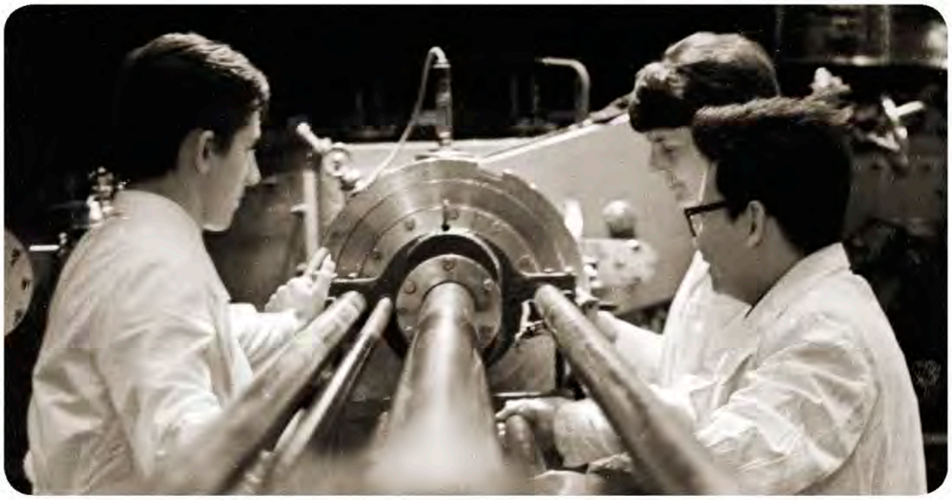
This robotic lunar buggy *was kept warm on the Moon's surface by the heat produced by the polonium inside it.*

Polonium is very radioactive: 1 g (0.03 oz) of this metal quickly heats up to 500°C (932°F) because of the radiation it emits. This element was discovered by Marie and Pierre Curie in 1898. Marie named it after Poland, her homeland. It is rare in nature, and is normally produced in nuclear reactors. Despite its radioactivity, this element is used in a few ways. It can trigger the explosion of **atom bombs**. It heats and powers spacecraft, such as the Russian **Lunokhod rovers**, which landed on the Moon in the 1970s.

116
Lv Livermorium



State: Solid
Discovery: 2000

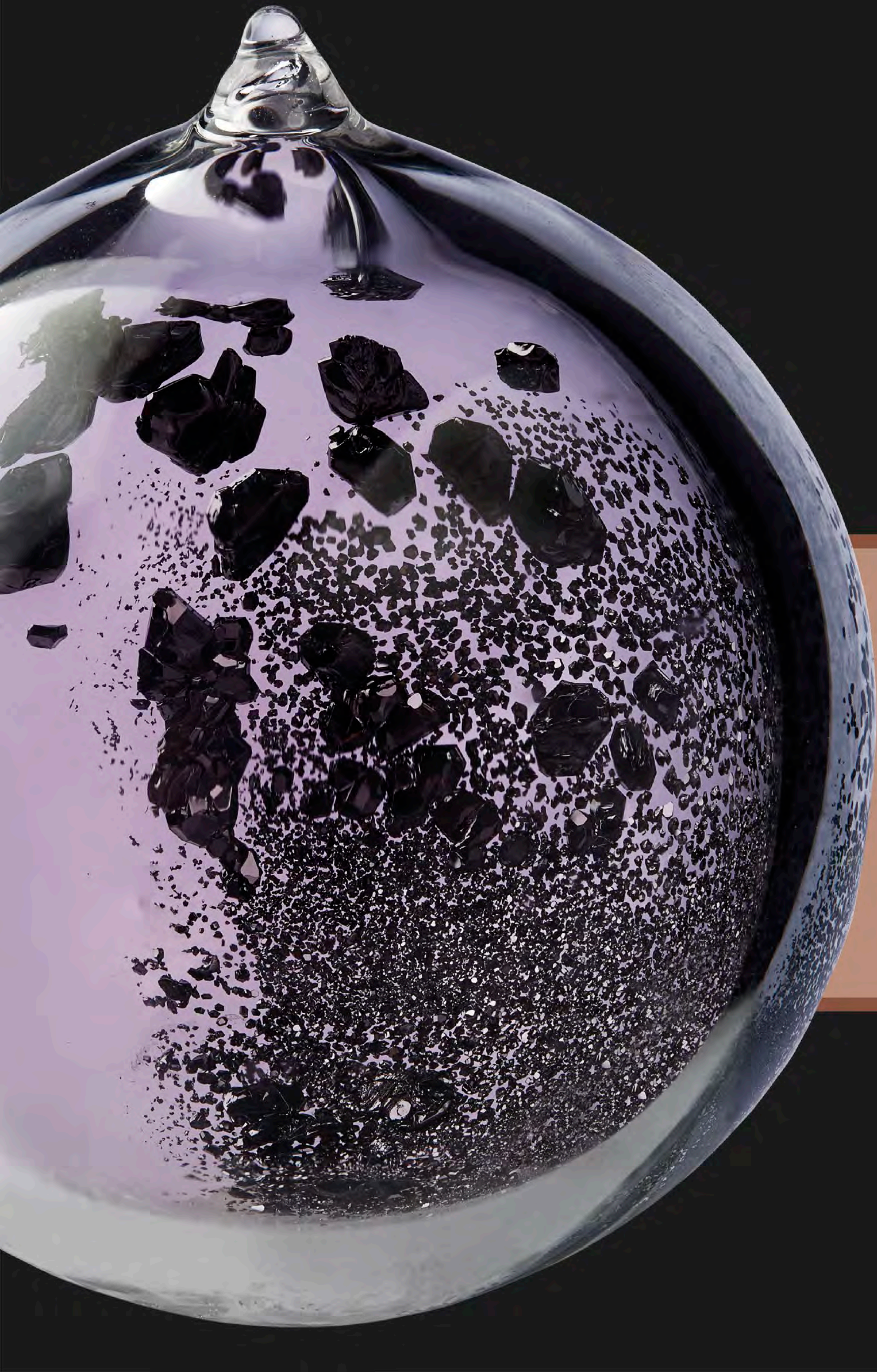


Heavy ion cyclotron,
Joint Institute of Nuclear Research, Dubna, Russia

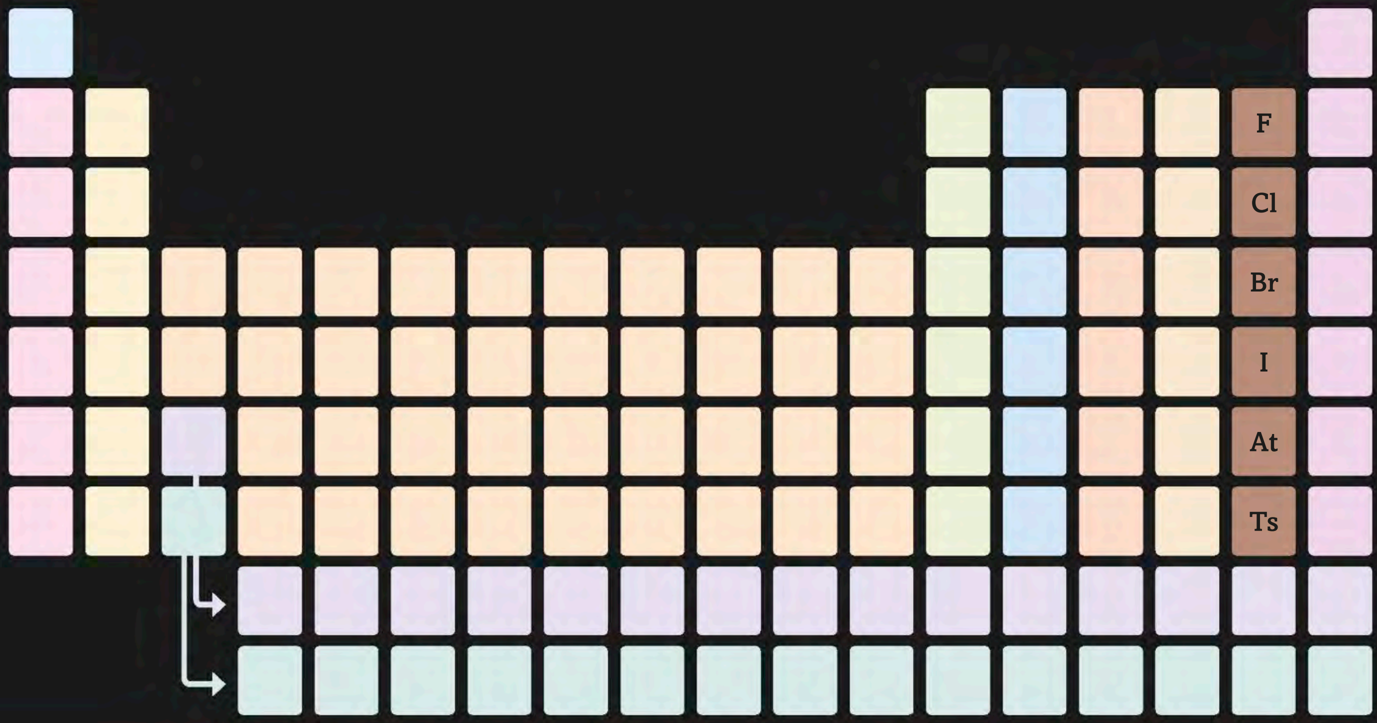
Livermorium has been **named after** this **laboratory**.

Lawrence Livermore National Laboratory, California, USA

When livermorium atoms were first produced in 2000, they broke apart in a fraction of a second. The first successful attempt to create atoms of this element was made at the **Joint Institute of Nuclear Research** at Dubna, Russia. The team worked with material provided by the **Lawrence Livermore National Laboratory** in California, USA. This highly radioactive element was produced by firing calcium atoms at curium atoms in a particle accelerator (a machine in which atoms are smashed together).



This glass sphere contains pure iodine (I).



The Halogen Group

One of the most reactive groups in the periodic table, this set includes non-metals. The name "halogen" means "salt former", which refers to the way that elements in this group react with metals to form salts, such as sodium chloride, widely known as common salt. Scientists don't know much about tennessine (Ts), an artificial halogen.

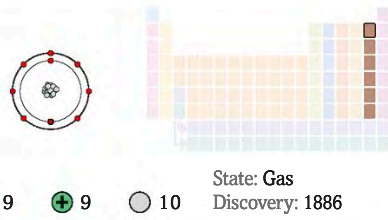
Atomic structure
All members have seven electrons in the outer shell of each atom. There is space for one more electron in each outer shell.

Physical properties
Bromine (Br) is the only halogen that is liquid. Fluorine (F) and chlorine (Cl) are gases, while iodine and astatine (At) are solids.

Chemical properties
Every halogen atom receives one electron from other atoms to form a compound. Reactivity decreases down the group.

Compounds
The halogens react with hydrogen (H) to form acidic compounds. Halogen compounds are used in products such as bleach.

9 F Fluorine



State: Gas
Discovery: 1886

Forms

This soft mineral *is brittle, which means it breaks easily into lots of pieces.*

Cryolite

Laboratory sample

This sealed case *contains a mixture of fluorine and helium.*

Topaz **means "fire"** in the ancient Indian language of Sanskrit.

These cubic crystals *are green due to impurities.*

Fluorite

Topaz

This precious gemstone *contains 20.7% fluorine.*

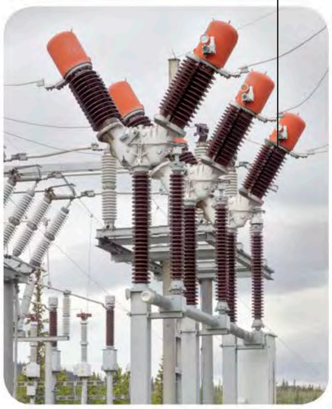
This highly reactive element is incredibly dangerous when pure: just a tiny amount added to the air can kill a person. A pale yellow gas, fluorine reacts with brick, glass, and steel, burning a hole straight through them. Because it is so dangerous, pure fluorine is often stored in nickel containers that can resist its attack. Minerals such as **cryolite** and **fluorite** contain this element. This gas and its less harmful compounds have a wide variety of uses. Hydrofluoric acid is a toxic liquid used to etch patterns on glass, as seen in some **glass vases**.

Uses

Etched glass vase

These patterns *form after the surface of the glass is burned by an acidic fluorine compound.*

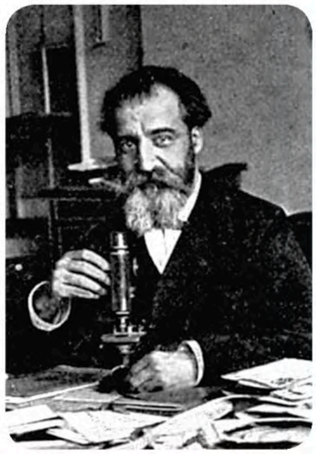
These circuit breakers*, containing a compound of fluorine and sulfur, cut electricity supply in an emergency.*



Circuit breakers

HENRI MOISSAN

In the early 1800s, chemists in Europe realized that minerals such as fluorite contained an unknown element. However, it took another 70 years before the French chemist Henri Moissan extracted pure fluorine following a series of dangerous experiments that even poisoned him several times.



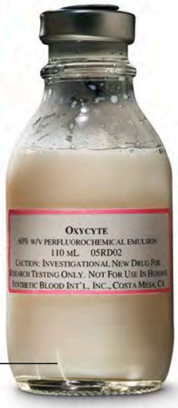
Ceramic pot

The shiny coating *on this ceramic dish is from a fluorine-containing glaze.*

Fluorine-rich plastic clothing *repels water.*

Waterproof clothing

Upon injection, this fluorine-rich liquid *heals damaged tissues by carrying oxygen to them.*



Oxycyte

PTFE was used by NASA to make **spacesuits** because it protected against heat.

This pan *has a PTFE coating that resists heat.*

Non-stick pan

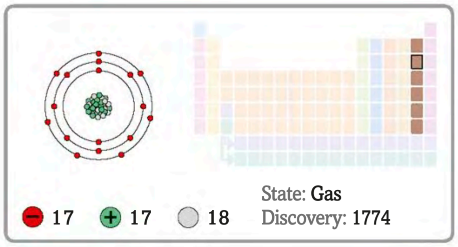
Some toothpastes *contain fluorides that harden tooth enamel.*

Toothpaste

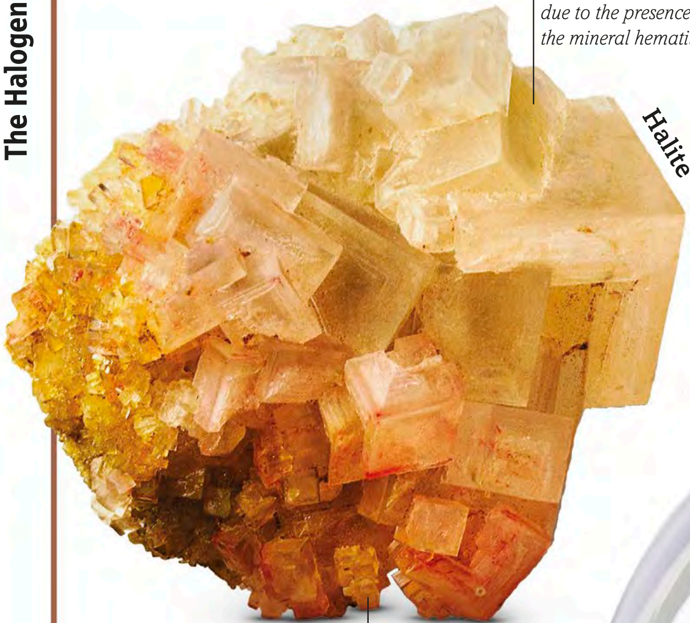
Some glazes used to coat ceramics contain fluorine minerals. When heated, these glazes release fluorine, which hardens the ceramic underneath. Another compound called polytetrafluoroethylene (PTFE) is commonly used to make **non-stick pans**: this material is slippery and prevents food that has burned while cooking from sticking to the pan. Thin fibres made of PTFE are also used to make lightweight, **waterproof clothing**. One of the most common uses of fluorine compounds is in **toothpaste**: they toughen teeth against decay.

17
Cl

Chlorine

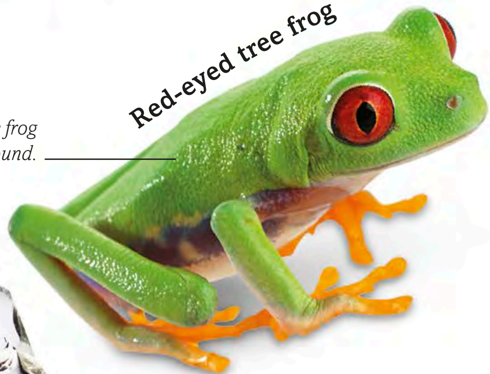


Forms



***This orange colour** is due to the presence of the mineral hematite.*

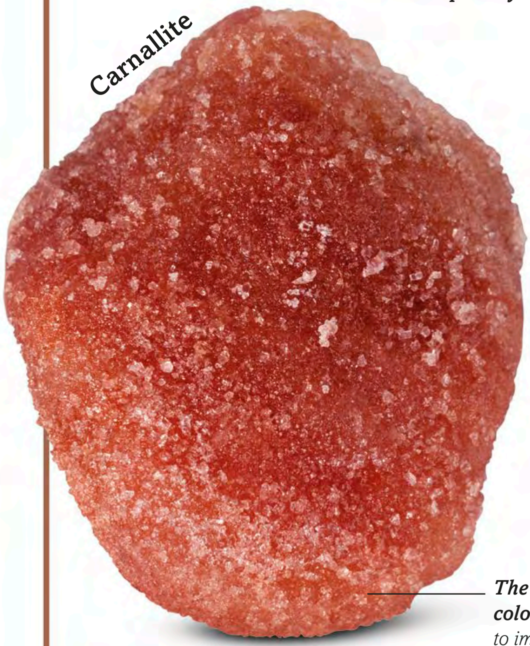
Cube-shaped crystals



***The skin** of this tree frog contains a chlorine compound.*

***This glass sphere** traps pure chlorine so as to prevent any reactions with air.*

***Pure chlorine** is heavier than air.*



***The intense red colour** is due to impurities.*

Chlorine is named after the Greek word *chlóros*, which means "pale green", a reference to the colour of this gaseous element. Chlorine is a highly reactive gas that forms a number of compounds, and does not exist pure in nature. The most common chlorine compound is sodium chloride, found in nature as the mineral **halite**. Chlorine compounds are important for the body and are used by muscles and nerves. They are also present in sweat. As it is poisonous in its pure form, chlorine gas was used as a weapon during World War I: soldiers had to wear masks for protection

Uses

Running shoes

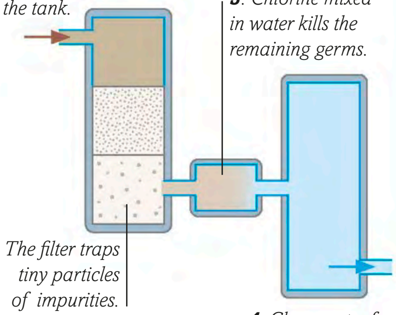
The soles of some running shoes *contain chlorine compounds.*

Sodium chloride *is used to season meals.*

Common salt

CHLORINATION

The process of cleaning dirty water with chlorine is called chlorination. This method involves passing the water through a filter.



Chloroform

Breathing in this chlorine-infused liquid *makes people fall unconscious.*

PVC pipes

Strong water pipes *are composed of thick PVC.*

Safety goggles

This chlorine-rich plastic *is tough.*

The chlorine levels in this pool *need to be regulated carefully to maintain the quality of water.*

Swimming pool

Bleach

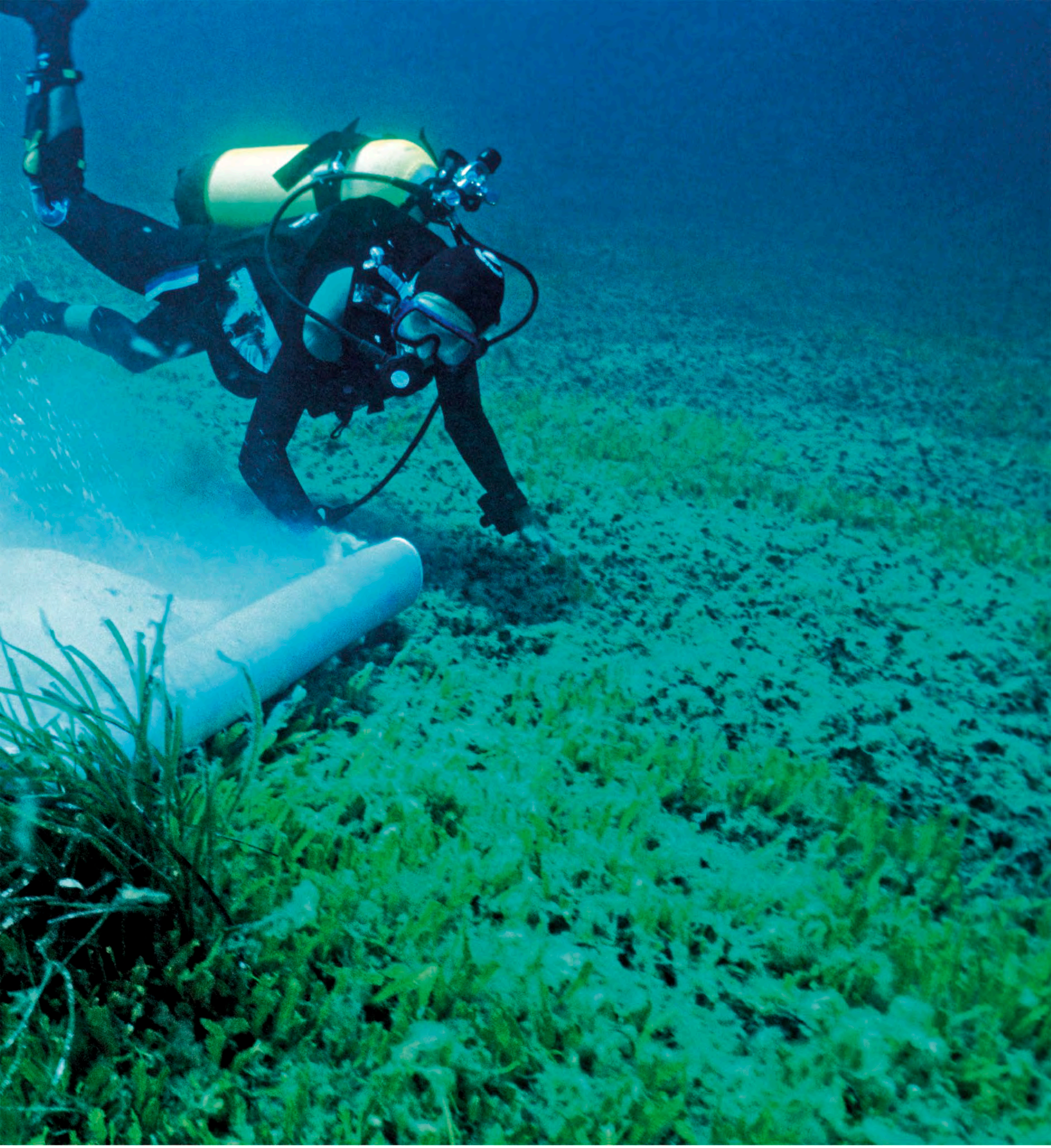
This bleach cleaner *contains a compound called sodium hypochlorite.*

PVC suitcase

This case *is tough but flexible.*

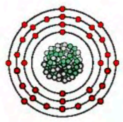
against this weapon. Today, chlorine is used in many ways. Its compounds are present in everything from **running shoes** to **choloroform**. It reacts with hydrogen to make hydrochloric acid, an industrial cleaner. This corrosive liquid eats away at most metals, releasing hydrogen gas. A weaker chlorine acid is used to clean water in **swimming pools**, while **bleach** and other cleaners use chlorine compounds to kill germs. One of the most widely used plastics, **polyvinyl chloride (PVC)**, contains chlorine. It is a tough plastic, used to make many rigid objects.

OCEAN CLEAN UP Chlorine is a common ingredient in cleaning products, and can be used for scrubbing everything from bathroom tiles to ocean floors. These divers are trying to remove harmful seaweed in the Mediterranean Sea using the power of chlorine. This green weed grows quickly and can potentially kill other sea plants by depriving them of their essential nutrients. Some fish are also poisoned if they eat this toxic weed.



The two divers use chlorine twice in the cleaning process. First, they cover the thick seaweed with a sheet made of PVC, a tough plastic containing chlorine. Next, they pump a compound of sodium and chlorine called sodium hypochlorite under the sheet. This powerful liquid bleach kills the unwanted seaweed. Several weeks later, the divers return to remove the PVC sheets. The invading seaweed will not regrow, and the plants on the seabed will gradually return. Although chlorine is highly reactive and can damage skin and other body parts, divers are well-protected by their rubber wetsuits.

35
Br
Bromine



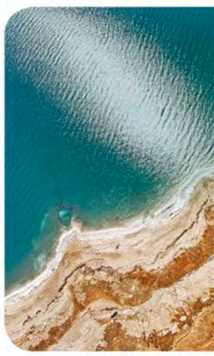

35 35 45

State: Liquid
Discovery: 1826

Forms

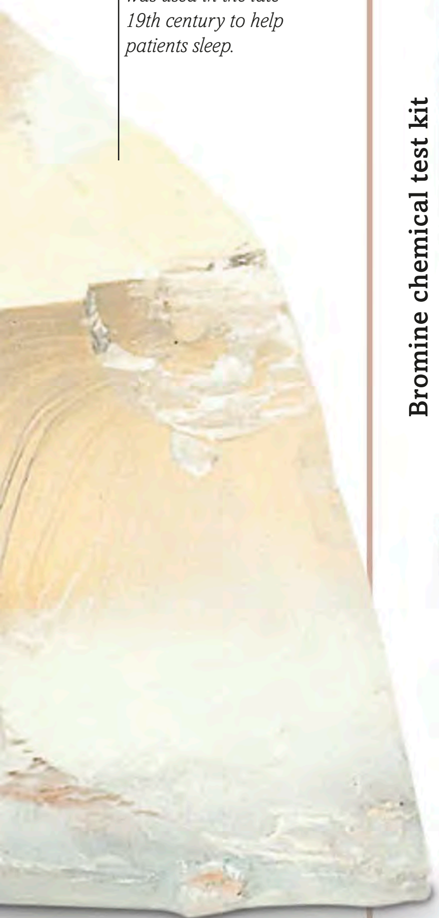

Potassium bromide

Bromine is named after the Greek word for **"stench"** because of its strong smell.

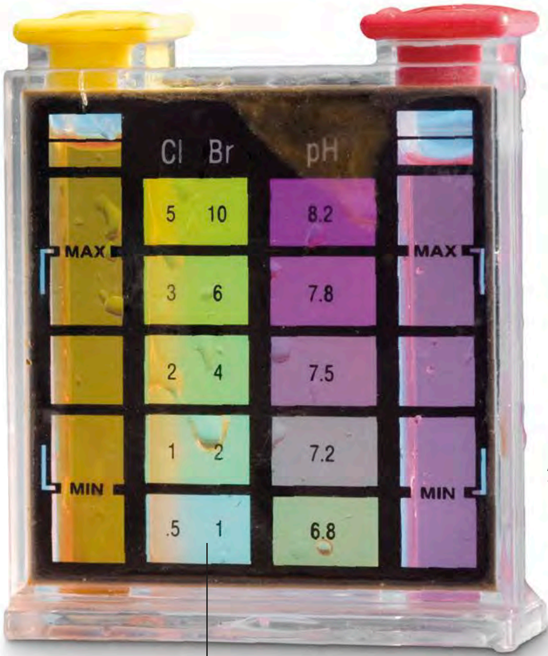


Bromine is the only non-metal that is a liquid at room temperature. A thick vapour given off by this liquid is dangerous if breathed in. **Pure bromine** is never found in nature. Its compounds can easily mix in water, and are found dissolved in seawater and extremely salty lakes, such as the **Dead Sea** in the Middle East. Solid bromine salts, including **potassium bromide**, collect as the water evaporates away, leaving behind crusts of white crystals. Bromine can then be extracted from the solid salts. A common

Uses



This bromine salt *was used in the late 19th century to help patients sleep.*



Bromine chemical test kit

The colours on this test kit *show how much bromine is in the water.*

Fire extinguisher

This fire extinguisher *uses a non-flammable, bromine-rich gas to extinguish fires.*

This image *was created when light reacted with silver bromide.*

Photograph negative

Bromine was used as a **weapon** in World War I.

The fabric *used to make this suit contains bromine compounds that make it fireproof.*

Fireproof suit

Crusts of bromine salts *form along the Israeli shoreline.*

The Dead Sea Coast

ANTOINE-JÉRÔME BALARD

In 1826, French chemist Antoine-Jérôme Balard discovered bromine. He heated seawater from salt marshes, and after most of the water had evaporated, he passed chlorine gas through what was left. The remaining liquid turned orange-red: this was bromine.

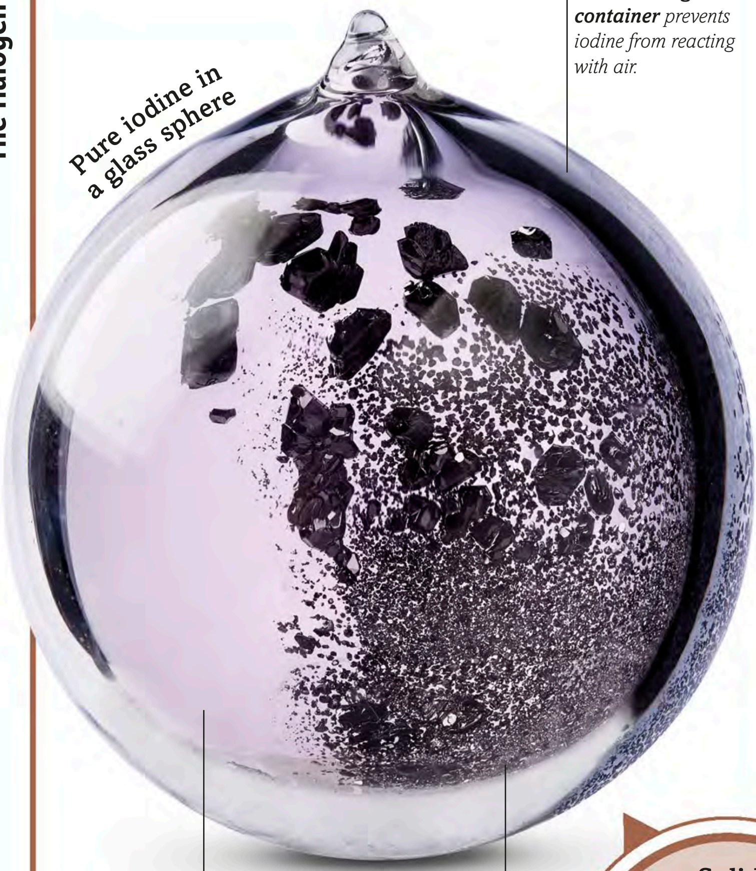
use of this element is as a disinfectant to clean water. It works better than chlorine in hot tubs as chlorine escapes into the air easily from the warm water. The concentration of bromine in swimming pools can be regulated using **chemical test kits**. Bromine compounds can be used in film photography in which images are printed using chemicals on **negatives**. Today, bromine is mainly used in **fireproof material**, such as firefighter suits or furnishings, because it doesn't catch fire easily.

53
I

Iodine

53 53 74
State: Solid
Discovery: 1811

Forms



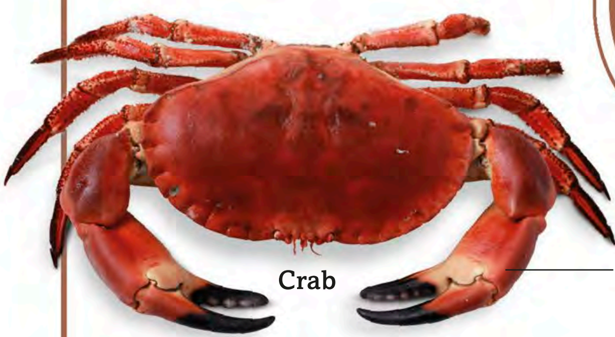
Pure iodine in a glass sphere

This sealed glass container *prevents iodine from reacting with air.*

Purple iodine vapour

Purple-black solid iodine

Solid iodine **does not melt** when heated, but turns into a vapour.



Crab

This crab *absorbs iodine from seawater.*

Uses

Printing ink

These coloured inks *are made using iodine compounds.*

Polarizing sunglasses

These lenses *contain iodine, which filters out bright, reflected light.*

Candied cherries

The bright red colour *of these cherries is due to an iodine dye.*

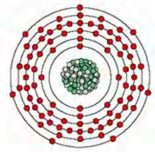
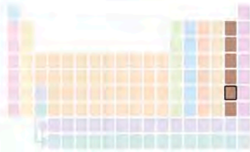
This disinfectant *is applied to wounds to stop the spread of infection.*

Betadine

Iodine is the only halogen that is solid at room temperature. The element forms a purple gas when heated, and is named after the Greek word *iodes*, which means “violet”. Iodine was first discovered in seaweed, and many plants and animals in the sea have high levels of iodine.

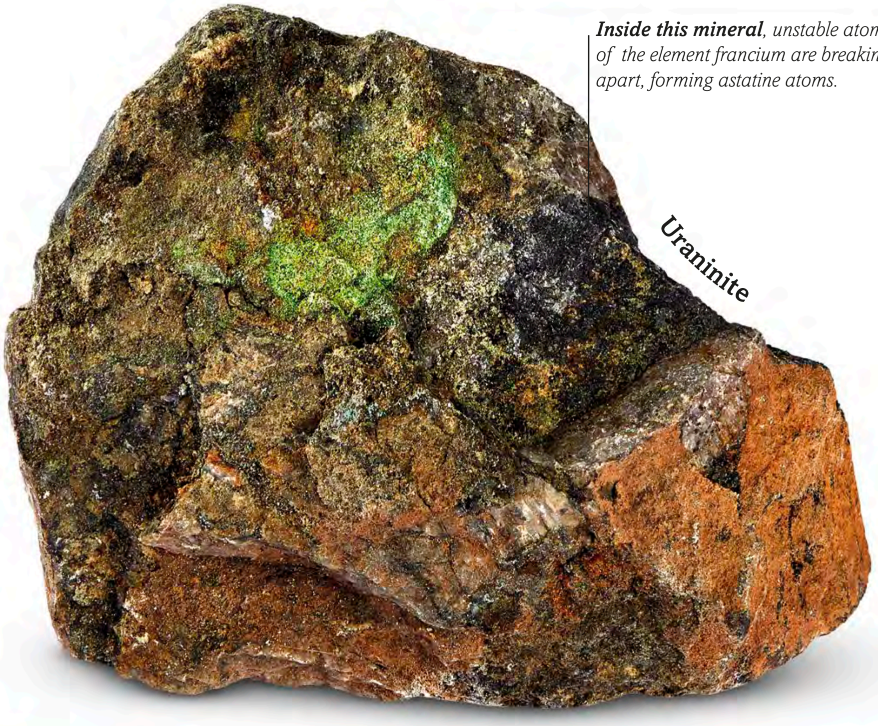
Seafood, including **crabs** and fish, provide the element in our diet. The human body needs small amounts of iodine to make an important substance called thyroxine, which helps us grow. Iodine is also used to make **printing ink**, red and brown food dyes, and disinfectants.

85
At
Astatine

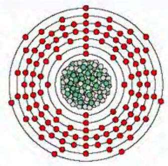
85 85 125
State: Solid
Discovery: 1940

Atoms of astatine are unstable, and typically break down after just a few hours, into atoms of lighter elements, such as bismuth. This radioactive element itself forms in a similar way when atoms of a heavier element called francium break apart. Tiny amounts of this rare element are found in uranium ores, such as **uraninite**. The Italian physicist Emilio Segrè was one of the first scientists to isolate a sample of pure astatine. He was able to do so by using a particle accelerator: this is a machine that smashes together atoms and then studies the results.



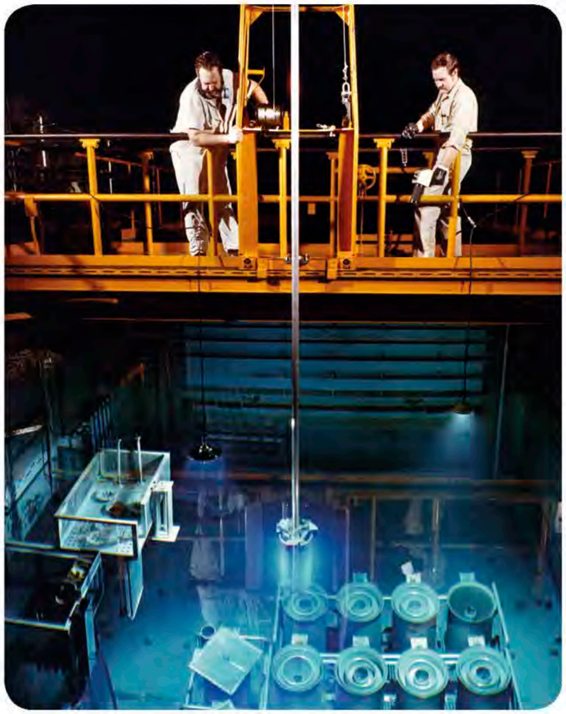
***Inside this mineral**, unstable atoms of the element francium are breaking apart, forming astatine atoms.*

117
Ts
Tennessine



117 117 177

State: Solid
Discovery: 2011 (predicted)

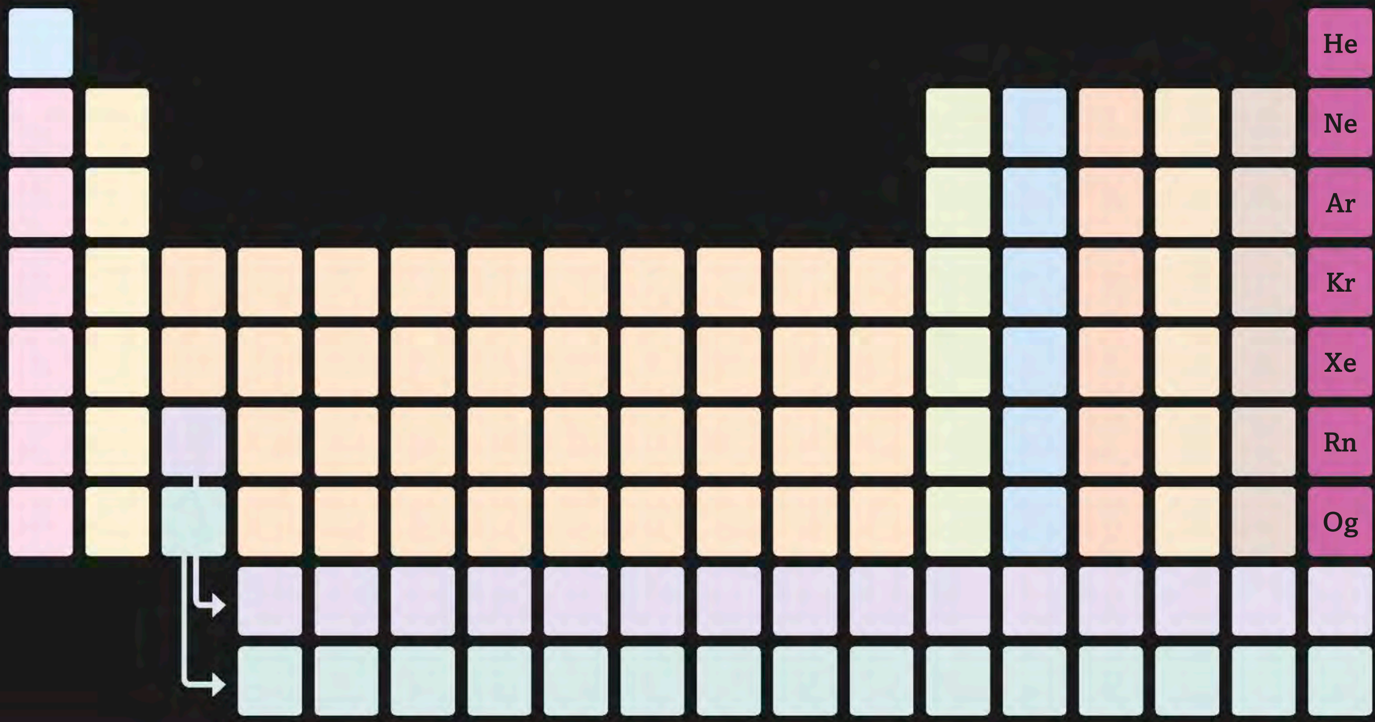


Nuclear Reactor, Oak Ridge National Laboratory, Tennessee, USA

Atoms of tennessine **existed for a few seconds** after they were formed.

Tennessine is the youngest element in the periodic table. It was produced in 2011, in the Russian city of Dubna. The element was named after the US state of Tennessee, home to the **Oak Ridge National Laboratory**, which houses one of the first, large-scale nuclear reactors ever built. Only a few atoms of this halogen element have ever been made. Even so, scientists have predicted it to be a semi-metal, not a non-metal like all the other halogens.

Krypton (Kr) becomes visible only when it is electrified.



Noble Gases

The group on the far right of the periodic table belongs to the noble gases. These elements are described as "noble" because they do not react with the other "common" elements, such as oxygen (O). Their atoms never form bonds in nature, not even with atoms of their own kind, and so they are always gases at room temperature.

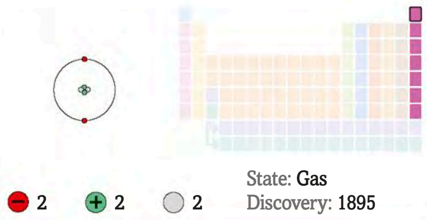
Atomic structure
Apart from a helium (He) atom that has two electrons in its outer shell, all other elements in this group have atoms with eight electrons.

Physical properties
All the members of this group are colourless gases. Going down the group, the density increases – radon (Rn) is 54 times denser than helium.

Chemical properties
Noble gases never react in nature. In the laboratory, heavier noble gases can be forced to form compounds with fluorine (F).

Compounds
These gases form no natural compounds. However, xenon (Xe), krypton (Kr), and argon (Ar) can be made to form compounds.

2 He Helium



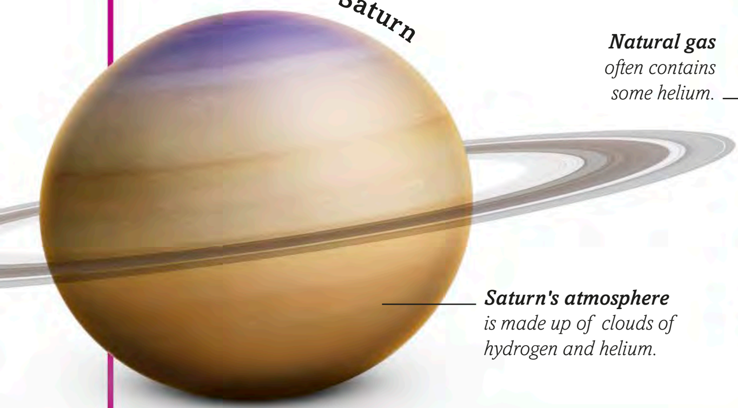
State: Gas
Discovery: 1895

Forms

This sample of helium *is trapped in a glass sphere.*

Pure helium in a glass sphere

Helium is a transparent gas*, but it glows purple when electrified.*



Saturn

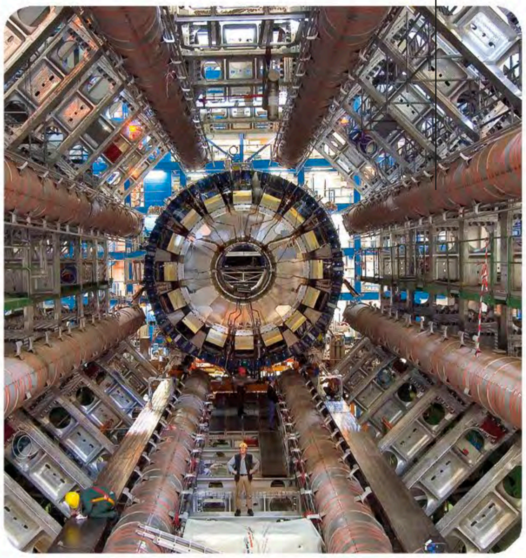
Saturn's atmosphere *is made up of clouds of hydrogen and helium.*

Natural gas *often contains some helium.*

Gas flare rig

Uses

A particle accelerator *is a machine that smashes atoms together: this one uses liquid helium to cool its parts.*



Large Hadron Collider, CERN, Switzerland

Helium-cooled MRI scanner

Helium is the second lightest element after hydrogen. This transparent gas was first discovered in 1868 by Sir William Ramsay, a Scottish chemist. Today, we know that a quarter of all the atoms in the Universe are helium. It is one of the main gases in the atmospheres of giant gas planets, such as **Saturn**. Being so light, however, helium is very rare on Earth: it escapes from our atmosphere into space. It was not until 1895 that chemists managed to collect a sample of helium gas coming from uraninite, a radioactive uranium mineral. Today, helium is

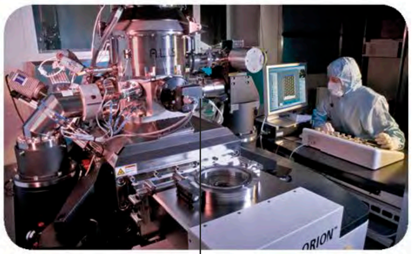
Airship

This airship contains large quantities of helium to make itself lighter than air.

Party balloon

This balloon contains a mixture of helium and air.

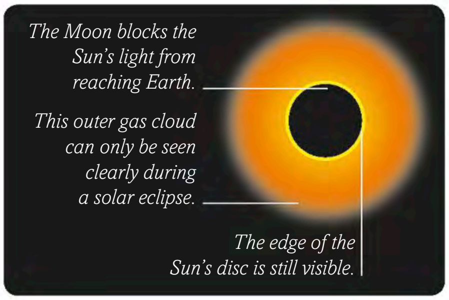
Helium-ion microscope



This powerful microscope can zoom in to view much smaller details than most other microscopes.

SUN GAS

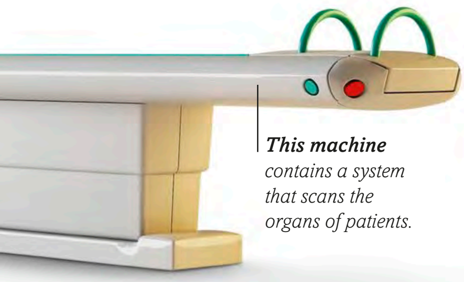
In 1868, during a total solar eclipse (when the Moon passes directly in front of the Sun), helium was discovered in the cloud of gas seen around the Sun. The yellow colour of this cloud showed it contained an unknown gas, which was named after Helios, the Greek god of the Sun.



This high-speed train uses a pair of magnets: one to move forward and one to float over the track.

The track is lined with a magnet that repels the one on the train, making it float.

Helium-cooled maglev train



This machine contains a system that scans the organs of patients.

Helium has the **lowest melting point** of any element.

Rocket helium tank

Helium in this container will fill up a rocket's fuel tanks as they empty out during liftoff.

collected from underground reservoirs or is found mixed in natural **gas** and oil. Unlike hydrogen, which is very reactive, helium is a noble gas and does not react at all. This property makes it safe to use in objects such as **party balloons** and **airships**. To turn helium into a liquid, it must be cooled to an extreme temperature of –269°C (–452°F). Liquid helium is used to make things very cold, including the powerful magnets used to make **maglev trains** float along special tracks. **MRI scanners** also use liquid helium for cooling.

NEBULA This glowing nebula (cloud of gas and dust) is the Crescent Nebula. It is so vast that our entire Solar System would fit inside it seven times over. The nebula's light comes from a super-heated star at its centre. Known as WR 136, this star is 15 times heavier than our Sun and 250,000 times brighter. Its immense power comes from its fuel – helium.

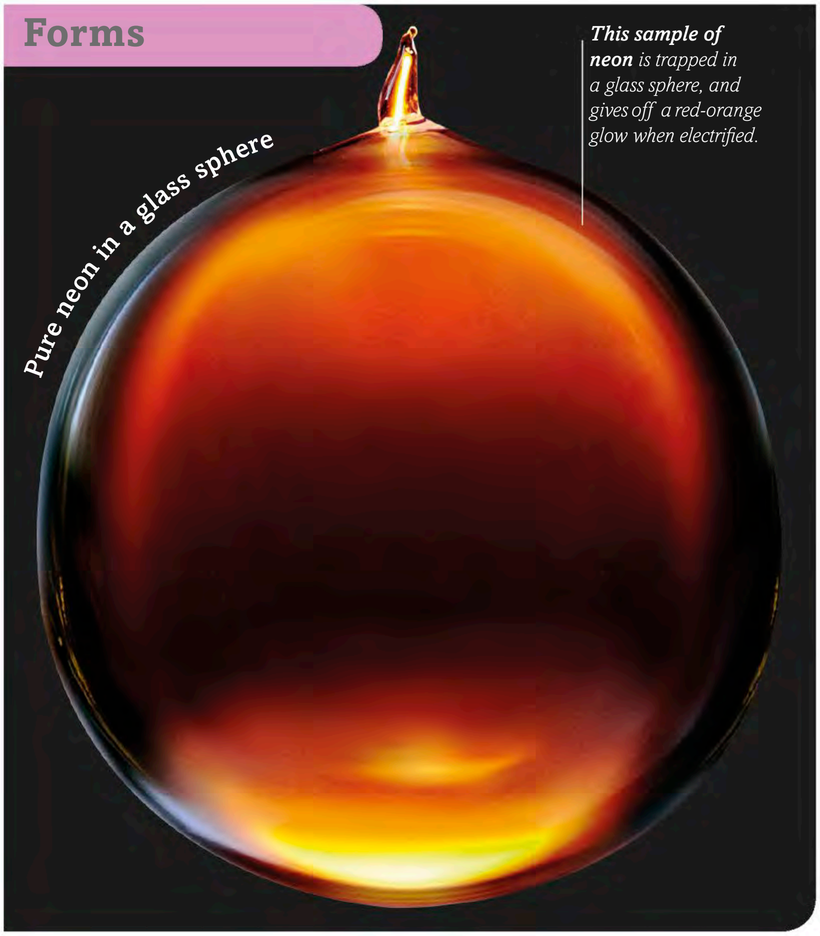
Helium makes WR 136 hot and bright. The star once burned using hydrogen, like our Sun. Hydrogen atoms smashed together in the star's core until they became helium atoms, releasing energy in the process. However, the star ran out of hydrogen about 200,000 years ago. It began smashing together helium atoms instead, and ballooned into a gigantic red star, sending out a cloud of gas that spread around it. The star is producing a wind of electrified gases that hurtles out at 1,700 km (1,056 miles) every second. This wind continues to crash into the gas cloud, making it glow into the nebula we see. Eventually, WR 136 will run out of helium and its other fuels, and explode into an enormous fireball called a supernova.

10
Ne
Neon

10 10 10

State: Gas
Discovery: 1898

Forms



Pure neon in a glass sphere

***This sample of neon** is trapped in a glass sphere, and gives off a red-orange glow when electrified.*

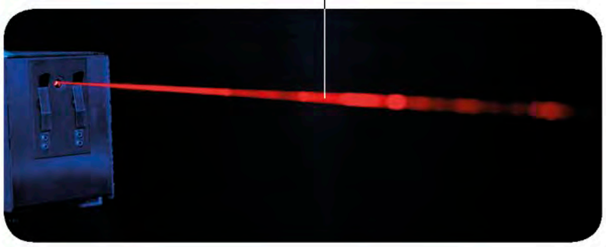
Volcanic eruption

***Volcanic eruptions** release neon gas into the atmosphere.*

Neon lights may refer to lighting produced using any noble gas.

Uses

***A deep red beam** is emitted by this laser.*



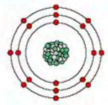
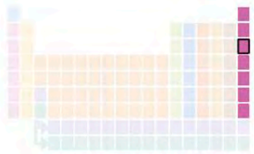
Helium-neon laser

***Glass tubes filled with neon** are used as brightly lit signs.*

Neon sign

Neon is a rare element: it makes up just 0.001 per cent of our atmosphere. Some of it was locked in Earth's rocks when the planet formed, and this is released into the air by **volcanic eruptions**. **Pure neon**, a transparent gas, is extracted by cooling air to a temperature of −189.34°C (−308.81°F), at which point the neon gas in the air turns to liquid. Neon can be mixed with helium to create research **lasers**. However, it is most commonly used in lighting, such as in **illuminated signs** or as bright warning beacons in the path of aircraft at airports.

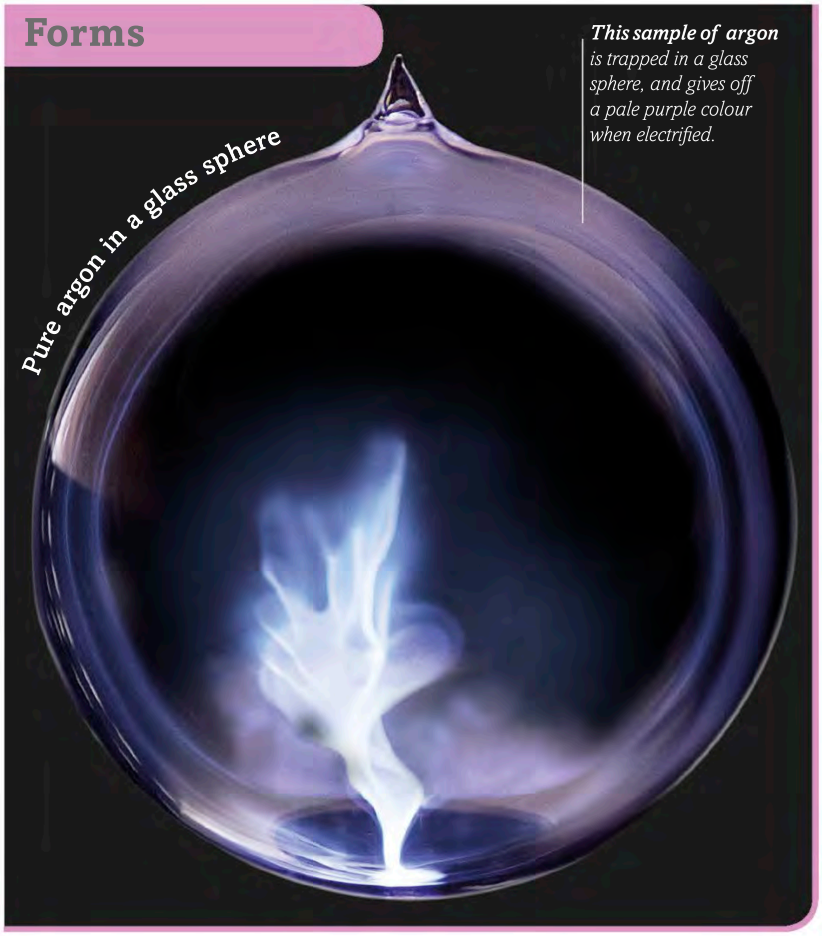
18
Ar
Argon

18 18 22

State: Gas
Discovery: 1894

Forms

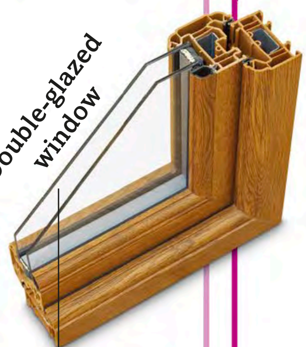


This sample of argon *is trapped in a glass sphere, and gives off a pale purple colour when electrified.*

The Magna Carta*, a historical document, is stored in argon, which forces out oxygen and water vapour that would damage the parchment.*

Uses

Some diving suits *are inflated with argon to retain heat in cold water.*

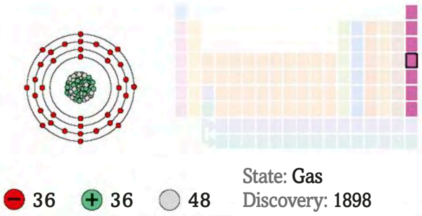


The space between the glass panes *is filled with argon to slow the loss of heat.*

Argon in this flame *prevents metals from reacting with oxygen*

Argon is the third most abundant gas in the atmosphere, after nitrogen and oxygen. It undergoes no reactions with any other element, and was named after the Greek word *argos*, meaning “idle”. Argon does not conduct heat well so it is put in **double-glazed windows**, and in **diving suits** during cold, deep dives. Its lack of reactivity is useful. Argon is used in **museum displays** to protect delicate exhibits. It also stops metals reacting during hot **welding**. This element can also be useful in the production of titanium.

36 Kr Krypton



State: Gas
Discovery: 1898

Forms

Pure krypton in a glass sphere

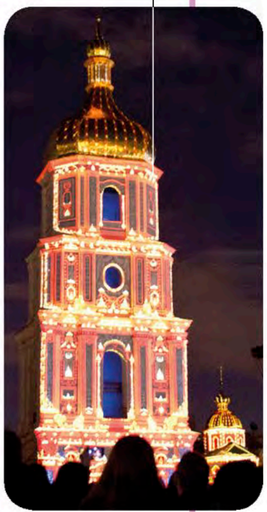
This sample of ***krypton*** *is trapped in a glass sphere.*

Krypton is a transparent gas *but it glows with a blue-white light when electricity flows through it.*

When this camera's flash *activates, it's a result of krypton being electrified by the camera's battery.*

Digital camera

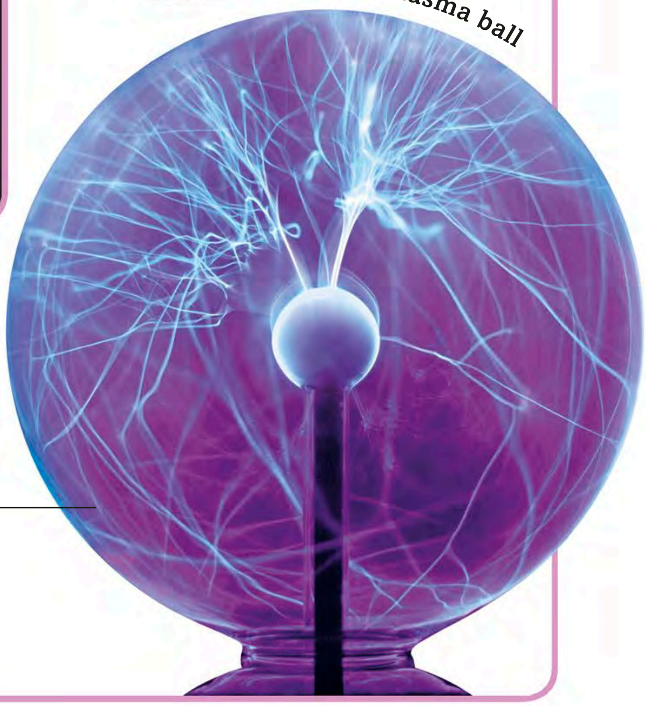
Krypton-based lasers *illuminate this building.*



Laser lighting

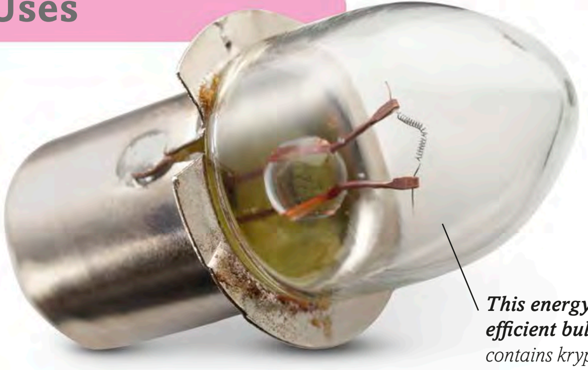
Sir William Ramsey won a **Nobel Prize** in Chemistry for discovering the noble gases.

Plasma ball



This globe *contains a mixture of noble gases, including krypton.*

Uses



This energy-efficient bulb *contains krypton.*

Incandescent bulb

The word krypton means the "hidden one" in Greek. This element exists as an inert gas in nature, which means that it does not react with almost any other element. Krypton is not found in any minerals and only tiny amounts of it can be found in the air. **Pure krypton** produces a very bright white light when electrified with a current, which makes it ideal for use in **flash bulbs**. Krypton can react with the element fluorine to form the compound krypton fluoride, which is used to power some kinds of **laser**.

54
Xe
Xenon

54 54 77

State: Gas
Discovery: 1898

Forms

Pure xenon in a glass sphere

Xenon is a transparent gas *but it glows with a blue light when an electric current flows through it.*

This sample of xenon *is trapped in a glass sphere.*

Anaesthesia machine

The xenon produced by this device *makes a patient unconscious before an operation.*

Xenon is used in powerful **lasers** that can **kill bacteria**.

Car headlight

Xenon headlights *glow brighter than the more common halogen headlights.*

Xenon lamp

Xenon glow *disinfects the air in a room.*

Uses

High pressure inside this lamp *makes electrified xenon glow very brightly.*

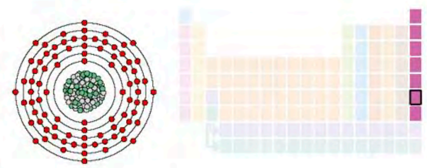
Modern film projector lamp

Dawn space probe

Electrified xenon *blasts from the exhaust, pushing the probe forwards.*

Xenon is so rare that there is only one atom of this gaseous element for every 10 million atoms in the air. Like the other noble gases, xenon is colourless and odourless. It glows brightly when electrified, making it useful in very powerful lamps, such as those used in **film projectors** and **car headlights**. The gas is harmless when breathed in and can be used as an **anaesthetic**. When preparing food, **xenon lamps** can purify the air. To propel spacecraft, xenon is used in some rocket engines that produce streams of fast-moving, electrified atoms.

86 Rn Radon



86 86 136 State: Gas Discovery: 1900

This uranium mineral *releases radon gas, as radioactive metals in it break apart.*

These yellow crystals *belong to another uranium mineral called uranophane.*

Radon is the only natural radioactive noble gas. This element is produced by the breakdown of uranium and other radioactive metals. Being a gas, radon escapes from minerals, such as **uraninite**, into the air. Radon is very radioactive and breathing it in can cause illness, such as lung cancer. In most places, the amount of radon in the air is incredibly tiny. However, its levels are high around **volcanic springs** and mud, where it bubbles out with other hot gases. Radon is also present in the water at **geothermal power plants**, which use heat energy from deep, volcanic rocks to make electricity. Radon is also more common in areas rich in granite rock. In these places, people use **test kits** to monitor their homes' radon levels.

It takes only 3.8 days for half of radon's atoms to split into atoms of other elements.

As it decays*, a compound called thorium dioxide emits radon.*

The muddy water *from volcanic springs contains radon.*

Hot springs in Lisvori, Greece

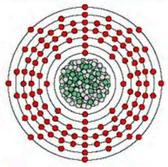
These pipes *draw water containing radon from deep under the ground, and this is then used to power the plant.*

Geothermal power plant

This kit *collects radon from the air so the amount of the gas in the area can be measured.*

Radon home test kit

118 Og Oganesson



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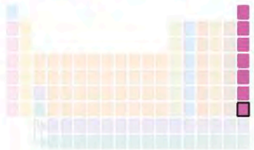
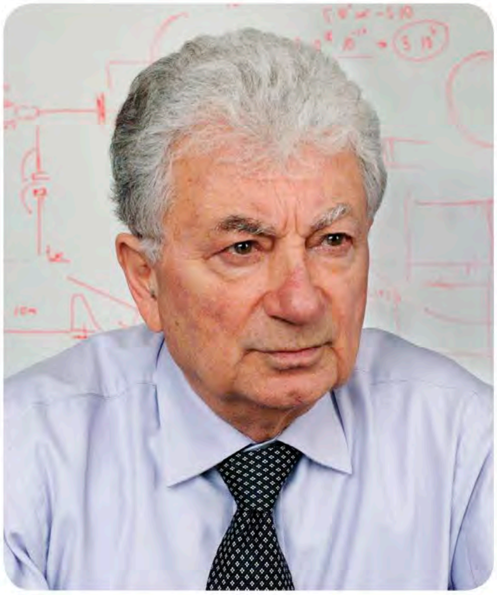


State: Solid
Discovery: 2006



Yuri Oganessian

The heaviest element yet made is oganesson. Scientists think it would be solid at room temperature, but it may really be an unreactive, noble gas. However, only a few atoms have been created so far, so its properties are not well understood. Oganesson was first produced by a team of Russian and American scientists who smashed californium and calcium atoms together at the **Joint Institute for Nuclear Research** in Dubna, Russia. The element was named after **Yuri Oganessian**, the leader of the team.

Joint Institute For Nuclear Research, Russia